Recommendation of Draft Revised Standard Calorific Value and Carbon Emission Factor for Fossil Fuel Energy Sources in Japan

2013 FY revised standard calorific value and carbon emission factor

OCTOBER 2014

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Abstract

Here the author quantified Japanese standard Gross Calorific Value and Carbon Emission Factor for various fossil fuels used in Japan upon the request of the Ministry of Economy, Trade and Industry and the Ministry of the Environment under the cooperation of relevant industrial organizations by the request of these Ministries, using real measured physical and chemical data and calorific value in 2013.

The revised standard values have several unique natures compared to the current one as follows;

- The standard values are comprehensive and clearly traceable from the real measurement data of physical, chemical characteristics and calorific value of fuels and the data process and treatment.

- The gross calorific value and carbon emission factors are simultaneously measured from the same samples in a consistent manner, different from the current standard values.

- The interpolation and approximation equations are estimated using these data and that enabled estimation for minor energy sources and adjustment of small changes of physical, chemical characteristics for major energy sources.

As a result, highly accurate and up to date standard gross calorific value and carbon emission factor are measured for various fossil fuels used in Japan listed in the current standard. So the author recommends the revision of the standard values.

Moreover, based on the revision works, the author proposes several changes and amendments of energy origin carbon dioxide emission quantification and estimation process in Japanese greenhouse gas inventory systems under the UNFCCC.

Key words; Fossil Fuel, Calorific Value, Carbon Emission Factor

JEL Classification: Q30, Q35, Q40

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[*] The analysis in this paper solely represent the author's view and opinions; they DO NOT represent RIETI IAA, Graspp of Tokyo University, UNFCCC-CDM Executive Board and other institute's view nor opinions.

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October 2014
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1. The Current Situation and Known Problems

1-1. Overview of current standard calorific values and carbon emission factors

1-1-1. Current standard calorific values

The current standard calorific values for different energy sources were set out as standard values in "Tables of standard calorific values by energy sources, fiscal year 2005" by the Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (ANRE/METI), which aggregated values in surveys of actual measurements, literature surveys and so forth with the cooperation of organizations associated with the METI.

In that standard calorific value tables, the standard calorific values are defined for a total of 60 energy sources, 29 in the main table and 31 in the reference table, from original units used for each energy source and gross (higher) calorific values for the original units. The standard calorific values were previously revised at roughly 5-year intervals and were intended to be revised at roughly 5-year intervals in the future. However, because fiscal year (FY) 2010 fell within the first commitment period of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) (2008–2012), the next revision (the current revision) was postponed till FY2013, after the end of the first commitment period.

For some of the energy sources, such as oil products, calorific values are calculated annually using various surveys and reports. These annual values are identified with the term "actual calorific values".

1-1-2. Current standard carbon emission factors

The current standard carbon emission factors for different energy sources were set as standard values in "Table of emission factors by energy source (FY1990 to FY2004)" in "GHGs Estimation Methods Committee Report" from the Global Environment Bureau, Ministry of the Environment (GEB/MOE). The validity of these values was verified by comparative surveys of various documents, such as the 2006 IPCC Guidelines[*1], working from the carbon emission factors set out in 1992 in "Report on Estimation of CO_2 Emissions in Japan" from the Global Environment Department, which was then under the Environmental Agency.

Of these carbon emission factors, the standard carbon emission factors for energy sources derived from fossil fuels such as coal, oil and natural gas are defined by reference to gross (higher) calorific values in accordance with the classes and original units in the Table of standard calorific values. When the validity of these standard carbon emission factors was checked in 2006, some of the values were revised and updated on the basis of values in the 2006 IPCC Guidelines[*2] and the like. However, most of the values, particularly of oil products, are still the same values as in the 1992 survey report.

There was no specific timeframe to update or revise the standard carbon emission factors at that time.

1-1-3. Calculating CO_2 emissions by energy source: standard calorific values and carbon emission factors

CO_2 emissions account for most of Japan's greenhouse gas emissions. In calculating CO_2 emissions by energy source, consumption amounts in the original units of energy sources are multiplied by the standard calorific values to calculate consumption amounts by energy source. These are then multiplied by the carbon emission factors and the carbon-to-carbon dioxide conversion factor.

To improve the accuracy of calculations of CO_2 emissions by energy source, we must improve the statistical accuracy of consumption amounts in sources such as "General Energy Statistics" and at the same time comprehensively and systematically improve the accuracy of the standard calorific values and carbon emission factors on which the calculations are based.

1-2. Problems with the current standard calorific values and carbon emission factors and the need for revision

1-2-1. Problems with the current standard calorific values and carbon emission factors

The standard calorific values and carbon emission factors described above in section 1-1 are used as the basis of calculations for Japan's National Greenhouse Gas Inventory, which is annually submitted to the UNFCCC Secretariat, and as standard values for various domestic systems such as the Act on Promotion of Global Warming Countermeasures and Act on the Rational Use of Energy. Particular care to ensure their accuracy is required.

[*1] IPCC; Intergovernmental Panel on Climate Change; see reference 7 for more about the Guidelines.

[*2] Some of the values used for carbon emission factors were taken from "Report of the Breakout Group on Energy and Industrial Processes" (2002), from the Committee for the Greenhouse Gases Emissions Estimation Methods, GEB/MOE. See reference 4 for details.

The current standard calorific values and carbon emission factors were calculated separately as described in section 1-1. In particular, the contractor for the 1992 survey has long since discarded the original documents that were the basis for the carbon emission factors. Therefore, we cannot now check and verify questions such as whether the standard calorific values and carbon emission factors are consistent with each other.

Because two decades have passed since the 1992 surveys of standard carbon emission factors, their values are less trustworthy now. Moreover, because the original documents have disappeared as mentioned above, it is not possible to take measures such as redoing the calculations. Consequently, experts conducting UNFCCC reviews have recommended several times that we should consider redoing the surveys.

1-2-2. The need for a fundamental revision of the standard calorific values and carbon emission factors

Although calorific values and carbon emission factors of energy sources are not the kind of values that essentially change by much from year to year, there may be changes over time in accordance with changes in the proportions of energy sources such as oil and coal, shifts in producing regions, different modes of production, and changes in the proportions of supply and demand covered by different product standards and specifications. When standard calorific values and carbon emission factors are established, degree of change and levels of accuracy must be verified periodically.

Standard calorific values and carbon emission factors are used as standard values in laws and ordinances such as the Act on Promotion of Global Warming Countermeasures and Act on the Rational Use of Energy. Depending on which government bodies and businesses are involved, revising the values frequently may be complicated and may cause unhelpful confusion. Therefore, unnecessary revisions must be avoided and the consistency of standard values that act as acceptable limits must be assured. Moreover, experimental measurements of calorific values and carbon contents of numerous energy sources are required but each such measurement costs tens of thousands of yen; so, there are inevitably budgetary constraints on revisions.

The above-described likelihood of accuracy falling with the passage of time is in conflict with the need for consistency of standard values and budgetary constraints. It is difficult to constantly satisfy these conflicting requirements.

Periodic revision at constant intervals, such as periodically revising the values at intervals of five years, is thought to be a practical solution to these problems.

1-2-3. The implementation of surveys for the current revision of standard calorific values and carbon emission factors and the object of this paper

In light of these issues, ANRE/METI and GEB/MOE decided to comprehensively and systematically survey and then revise the standard calorific values and carbon emission factors to be considered for application from FY2013. In FY2011 and FY2012, with the cooperation of relevant industrial organizations, a pre-survey was begun into questions such as the possibilities of obtaining physical properties and measured values and of obtaining samples for measurement.

In FY2013, the results of this pre-survey were received[*3] and the implementation of the actual survey was initiated, including obtaining measured values such as physical properties for various energy sources through the cooperation with the relevant industrial organizations and using provided samples and the budgets of the two ministries for measurements of physical properties.

The object of this paper, at the request of the two ministries, is to comprehensively and systematically calculate new standard calorific values and carbon emission factors to be applied from FY2013, by converting the physical values for energy sources obtained by the actual survey in FY2013 to calorific values and carbon emission factors, realigning these values, and statistically analyzing the values.

[*3] The results of the pre-survey are not published because they include content that is subject to the commercial confidentiality of businesses associated with the relevant industrial organizations.

2. Methodology of the Revision

2-1. Calculation criteria, calculation methods, and comparison and verification methods

2-1-1. Calculation criterion 1: Continuity with the previous system of gross (higher) calorific values and corresponding carbon emission factors in the original units

For continuity with the previous standard values of standard calorific values and carbon emission factors, I used the same units as before—kg, L or m^3—for each energy source and used the gross (higher) calorific value (GCV) [*4], which is the energy per original unit measured in MJ, and the corresponding carbon emission factor (CEF-G), which is the carbon emission amount per unit of energy measured in gC/MJ.

2-1-2. Calculation criterion 2: Consistency of standard conditions with standard ambient temperature and pressure

"Standard ambient temperature and pressure" (SATP: 25°C (298.15 K), 10^5Pa) [*5*6] was employed as the standard conditions for gases, liquids, etc. in the calculations of standard calorific values and carbon emission factors, except where specified otherwise.

2-1-3. Calculation criterion 3: Consistency of "with moisture and ash" and "wet coal" measurement standards

In measurement standards for calculations for solids such as coal and coal products, the condition "with moisture and ash" or "wet coal"[*7], which includes all moisture and ash components, was applied except where specified otherwise.

2-1-4. Calculation methods 1: "Pure component weighted averaging" and "direct measurement of heat, etc."

(1) Gases: pure component weighted averaging

For an energy source that is a gas or the like, where component amounts could be measured by gas chromatography, the theoretical calorific values and carbon emission factors of pure materials were calculated for components such as methane and propane, by using physical properties such as the standard enthalpy of formation; standard calorific values and carbon emission factors were calculated by averaging weighted by statistical processing of the component amounts [*8].

(2) Solids and liquids: direct measurement of heat, etc.

For an energy source that is a solid or a liquid to which method (1) cannot be applied, physical properties such as gross (higher) calorific value and carbon content or the like were directly measured and the results statistically processed to calculate the standard calorific values and carbon emission factors[*9].

2-1-5. Calculation methods 2: Calculating the net (lower) calorific value, calorific value by mass and 95% confidence interval as reference values

For the current revision of the standard calorific values and carbon emission factors, the following values were calculated as reference values to facilitate comparisons with the current standard values

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[*4] See Addendum 1 for an explanation of the relationships between gross (higher) calorific value, net (lower) calorific value and the corresponding carbon emission factors taking the specific example of ethanol.

Gross (higher) calorific value:	GCV
Net (lower) calorific value:	NCV
Carbon emission factor, gross or net:	CEF-G or CEF-N

[*5] In the 2005 table of standard calorific values, the standard conditions used are normal conditions (0°C (273.15 K), 1 atm). Therefore, care should be taken over the effects of this change in standard conditions on the calorific values and carbon emission factors of gases and liquids. In general, because the temperature in SATP conditions is higher than in the normal conditions, calorific values tend to be slightly smaller and carbon emission factors tend to be larger.

[*6] The reason for using SATP as the standard conditions is that SATP is currently being used for calculations of many coefficients in the field of physical chemistry. For example, SATP is the standard conditions for most of the various physical chemistry coefficients listed in the current Chronological Scientific Tables from the National Astronomical Observatory of Japan (see reference 1).

[*7] See Addendum 3 for details of these measurement standards.

[*8] This calculation method is below referred to as "pure component weighted averaging". Composition analysis by gas chromatography is widely used for analysis. We have been assisted by composition analyses being provided by relevant industrial organizations applying gas chromatography. Therefore, the actual number of useful samples could be greatly increased: as a result reliability was improved. See Addendum 1.

[*9] This calculation method is below referred to as "direct measurement of heat, etc.". Energy sources differ in the specific values that are measured and in the measurement methods. Accordingly, details are described in the respective entries for the energy sources in section 3 below.

and the 2006 IPCC Guidelines, etc.

(1) Calculating net (lower) calorific values and corresponding carbon emission factors as reference values

The net (lower) calorific values (NCV) and corresponding carbon emission factors (CEF-N) were calculated as reference values for all energy sources for which the calculation was possible.

(2) Calculating calorific value by mass as a reference value

For energy sources for which the original unit is a volume (L or m^3), the calorific value by mass (MJ/kg) was calculated as a reference value from the gross (higher) calorific value and net (lower) calorific value.

(3) Calculating upper and lower limits of 95% confidence intervals

For all energy sources for which the calculation was possible, respective upper and lower limits of the 95% confidence intervals were calculated for the gross (higher) calorific value and corresponding carbon emission factor and for the net (lower) calorific value and corresponding carbon emission factor.

2-1-6. Comparison and verification: comparison and verification against the current values and the 2006 IPCC Guidelines

For the current revision of the standard calorific values and carbon emission factors, in order to check the validity of the calculation results, the results from section 2-1-5 were compared with and verified against[*10] the current standard values or the 2006 IPCC Guidelines as described below for all applicable energy sources.

(1) The gross (higher) calorific value and corresponding carbon emission factor (GCV, CEF-G)

The newly calculated gross (higher) calorific values and corresponding carbon emission factors were compared and verified against the current standard values and the actual calorific values from 2012.

(2) The net (lower) calorific value and corresponding carbon emission factor (NCV, CEF-N)

The newly calculated net (lower) calorific values and corresponding carbon emission factors were compared and verified[*11] against the international default values in the 2006 IPCC Guidelines.

2-2. Selecting which values to calculate and which calculation methods to apply

2-2-1. Prioritizing energy sources with a view to accuracy: quantitative indices

For 39 energy sources, excluding electric power and heat, the actual measured values in General Energy Statistics are currently used. However, there are varying degrees of uncertainty about the standard calorific values and carbon emission factors of the energy sources and there are great differences between the energy sources in regard to energy supply and demand quantities such as total primary energy supply amounts and final energy consumption amounts.

When the effects on accuracy in General Energy Statistics and Japan’s National Greenhouse Gas Inventory are considered, problems seem to arise where the product of a "supply and demand amount" of an energy source multiplied with an "uncertainty" of a standard calorific value or carbon emission factor is large.

In light of this understanding, supply and demand amounts by energy source and uncertainties were estimated for each energy source as described below and quantitative indices for prioritizing accuracy were specified as described below.

Supply and demand amounts by energy source, Xi

The supply and demand amount of each energy source was taken as the most recent five-year average (FY2006–2010) in General Energy Statistics of whichever was the larger of total primary energy supply plus energy conversion production amounts or final energy consumption.

Uncertainties of calorific values and carbon emission factors by energy source, Uhi and UCi

Variation coefficients of the international default calorific values and carbon emission factors in the 2006 IPCC Guidelines were calculated based on Kainou (2005)[*12]. These were treated as uncertainty coefficients of the calorific values and carbon emission factors of each energy source.

[*10] See Addendum 2 for specific methods of comparison and verification against the current standard values and the 2006 IPCC Guidelines.

[*11] The 2006 IPCC Guidelines do not specify conditions such as temperature and pressure for the net (lower) calorific values and corresponding carbon emission factors, although standard conditions of 0°C, 1 atm are implied. For such reasons, it is difficult to completely align standards for comparison and caution is required.

[*12] See reference 8.

In Kainou (2005), where values could not be obtained directly, uncertainty coefficients of comparable energy sources were used. Where even such values could not be obtained, the uncertainty coefficient was set to 10%.

[Equation 2-2-1. Quantitive indices for prioritizing energy sources with a view to accuracy]

$$Di = Xi * (Uhi * UCi)^{0.5} \qquad \ldots\ldots \text{(Equation 2-2-1}$$

Di: Index of the effect of accuracy for energy source i
Xi: Annual supply and demand amount of energy source i (TJ/year, 5-year average)
Uhi: Uncertainty of calorific values of energy source i
UCi: Uncertainty of carbon emission factors of energy source i

2-2-2. Prioritizing energy sources with a view to accuracy: calculation results

The results of actually using the annual numbers in General Energy Statistics to calculate the quantitive indices are shown below. From these results, it can be seen that the energy source for which accuracy has the greatest effect on energy supply and demand and carbon emissions throughout Japan is crude oil for refinery use, which has the largest domestic supply and demand amount. In contrast, the 14 energy sources from imported anthracite down have small supply and demand amounts or small uncertainties. Consequently, they have relative effects of less than 5% the effect of crude oil for refinery use and can be considered relatively unimportant for accuracy.

[Table 2-2-2-1. Calculation results of quantitive indices for prioritizing energy sources with a view to accuracy]

Energy source	Index	Supply/ Demand	Uncertainty		Relative index	Energy source	Index	Supply/ Demand	Uncertainty		Relative index
	Di	Xi(PJ)	Uhi	Chi	(Crude oil=100)		Di	Xi(PJ)	Uhi	Chi	(Crude oil=100)
Crude oil for refinery use	140.8	8027	0.02	0.02	100	Petroleum coke	11.0	138	0.03	0.03	8
Steam coal for power generation use	104.0	2104	0.09	0.03	74	Kerosene	9.5	794	0.02	0.01	7
Coking coal	88.1	1649	0.07	0.04	63	Jet fuel	8.5	526	0.02	0.02	6
LNG	72.6	3674	0.02	0.02	52	Fuel oil A	7.6	778	0.01	0.01	5
Coke	57.4	1238	0.04	0.05	41	Other heavy oil products	6.4	283	0.06	0.01	5
Imported steam coal	45.6	921	0.09	0.03	32	Imported anthracite	5.5	148	0.09	0.02	4
Gasoline	35.3	2025	0.02	0.02	25	Crude oil for power generation use	4.9	279	0.02	0.02	3
Blast furnace gas for general use	34.0	315	0.09	0.13	24	Fuel oil C for power generation use	4.9	447	0.01	0.01	3
Town gas	31.9	1615	0.02	0.02	23 *1	RPF	3.3	33	0.10	0.10	2 *2
Naphtha	20.9	880	0.02	0.02	15	Indigenous natural gas	3.1	158	0.02	0.02	2
Black liquor	19.8	198	0.10	0.10	14 *2	Waste woods	3.0	30	0.10	0.10	2 *2
NGL/condensate	18.6	401	0.04	0.05	13	Coal tar	2.3	43	0.04	0.07	2
Refinery gas	15.4	675	0.05	0.01	11	Lubricant oil	2.0	102	0.04	0.01	1
Gas/diesel oil	14.6	1644	0.01	0.01	10	Waste tire	1.3	13	0.10	0.10	1 *2
PCI coal	14.6	295	0.09	0.03	10	Waste plastics	1.1	11	0.10	0.10	1 *2
LPG	14.4	710	0.03	0.02	10	Converter furnace gas	0.7	74	0.01	0.01	1
Fuel oil C	13.0	1197	0.01	0.01	9	Fuel oil B	0.1	2	0.01	0.01	0
Blast furnace gas for power generation use	12.9	119	0.09	0.13	9	(Reference values)					
Asphalt	11.5	260	0.03	0.06	8	(Electricity	0.0	3517	0.00	0.00	0)
Coke oven gas	11.5	364	0.03	0.03	8	(Heat	0.0	794	0.00	0.00	0)

Notes: *1 Using the uncertainty of imported natural gas (LNG); *2 Actual value unknown: 10% assumed

2-2-3. Selection of methods for calculating standard calorific values and carbon emission factors of energy sources

In light of the results of the pre-survey by ANRE/METI and GEB/MOE described in section 1-2-3 and the quantitive results for prioritizing with a view to accuracy in section 2-2-2, calculation methods for the standard calorific values and carbon emission factors of the energy sources were selected using the four selection criteria described below.

Selection criterion (1): The possibility of direct calculation from theoretical values

Selection criterion (2): The possibility of obtaining measurements or of cooperation from relevant industrial organizations
Selection criterion (3): The possibility of estimating from the values of other major energy sources
Selection criterion (4): The importance of measurements based on priority with a view to accuracy

The calculation methods for each energy source, which are the results of applying these selection criteria, are described in detail in the entries for the individual energy sources in section 3 below.

[Fig. 2-2-3-1. Selection criteria for calculation methods of standard calorific values and carbon emission factors of energy sources]

Selection criterion (1): The possibility of direct calculation from theoretical values

Can the calorific values and carbon emission factors of the energy source be calculated directly from theoretical values?

Possible → Class I: Calculate from theoretical values and published statistics
(LPG, LNG, electricity, heat)
Difficult → Proceed to selection criterion (2)

Selection criterion (2): The possibility of obtaining measurements or of cooperation from relevant industrial organizations

Does the pre-survey confirm that cooperation to obtain measurements for the energy source can be received from a relevant industrial organization?

Confirmed → Class II: METI or MOE requests cooperation and calculations are performed with obtained measurements
(Coking coal, coke, steam coal, refinery gas, indigenous natural gas, black liquor, etc.)
Unconfirmed → Proceed to selection criterion (3)

Selection criterion (3): The possibility of estimating from the values of other major energy sources

Can the calorific values and carbon emission factors of the energy source be estimated from the values of other major energy sources by weighted averaging, regression analysis or the like?

Possible → Class IV: Calculate by estimation from the values of another major energy source or from weighted averaging or regression analysis
(Town gas, imported anthracite, naphtha, fuel oil B, asphalt, etc.)
Difficult → Proceed to selection criterion (4)

Selection criterion (4): The importance of measurements according to the priority with a view to accuracy

Is the energy source a "relatively important" energy source whose quantitive index for prioritization with a view to accuracy according to section 2-2-2 is at least 5?

Important → Class III: Measurements are carried out by METI or MOE
(Major oil products: crude oil for refinery use, gasoline, gas/diesel oil, etc.)
Not important → Class V: Survey the literature. If values are found, update to them. If values are not found, keep the current values
(Waste tires, waste plastics, coal tar, RDF, etc.)

2-3. Plotting interpolation and approximation expressions for calorific values and carbon emission factors

2-3-1. Plotting interpolation and approximation expressions for relationships of chemical compositions and physical characteristics with calorific values and carbon emission factors

Fundamentally, if an energy source with a particular chemical composition and physical characteristics is completely combusted, assuming the measurement conditions are SATP, any measured calorific values and carbon emission factors are uniquely determined regardless of the location and time of measurement.

However, for actual energy sources such as coal and oil products, the chemical composition and physical characteristics, and relative proportions thereof, may change over time for various reasons such as raw material conditions on the upstream side and product supply and demand and quality regulations on the downstream side. Therefore, the average values of standard calorific values and carbon emission factors for an energy source will gradually change over time.

Therefore, if the relationships of chemical composition and physical characteristics of an energy source with the calorific values and carbon emission factors can be accurately determined, then if the chemical composition and physical characteristics or relative proportions change slightly in the future, it will be sufficient to recalculate interpolated values on the basis of those relationships and there will be no need to repeat the current large-scale measurement work.

In addition, if the calorific values and carbon emission factors of some energy sources can be estimated from the values of other major energy sources as described in section 2-2-3, the cost and effort of carrying out measurements may be saved with no more than a minimal loss of accuracy.

In this light, the relationships of chemical compositions and physical characteristics with calorific values, carbon emission factors and the like are analyzed for typical energy sources in this paper using regression analysis, and interpolation and approximation expressions are plotted[*13].

2-3-2. Energy sources for which interpolation and approximation expressions are plotted

The energy sources for which interpolation and approximation expressions are plotted include energy sources to which the pure component weighted averaging mentioned in section 2-1-4 can be applied and energy sources that meet selection criterion (1), "direct calculation from theoretical values is possible", in section 2-2-3. However, energy sources for which providing interpolation and approximation expressions would not be useful, because the chemical composition and physical characteristics are well known and direct recalculation is possible, are excluded.

A precondition for plotting interpolation and approximation expressions between chemical composition and calorific values, carbon emission factors and the like is that a substantial number of samples can be obtained by measurement. In this paper, the following three energy sources satisfy these two sets of requirements and are the subjects of plotting.

- Imported steam coal
- Crude oil for refinery use (including NGL/condensate)
- Major oil products

2-3-3. Comparison and evaluation of methods for plotting interpolation and approximation expressions

Methods for plotting interpolation and approximation expressions include regression analysis using gross (higher) and net (lower) calorific values and carbon emission factors as dependent variables and typical composition analysis and physical characteristics as independent variables, and regression analysis using gross (higher) and net (lower) carbon emission factors as dependent variables and the corresponding calorific values as independent variables.

Statistical accuracy evaluation indices are then calculated from the results of the regression analyses and compared. Interpolation and approximation expressions[*14] with high accuracy are selected for use in estimation.

[*13] Standard expressions for estimating the calorific values of oil and oil products from physical characteristics such as density, sulfur content, water content, ash content, etc. are already included in JIS K2279, etc. However, there are no such approximations for other energy sources or for the carbon emission factors.

[*14] The accuracy of the newly plotted interpolation and approximation expressions for oil and oil products can be compared with JIS K2279. Accordingly, these were compared and verified.

3. Results (1) Coal and Coal Products

3-1. Coal

3-1-1. Imported steel making coal

(1) Calculation method and sample sources

Sample sources:

Calculated values for coking coal and pulverized coal injection (PCI) coal

Steel making coal consumption amounts from General Energy Statistics FY2008–2012

Calculation method:

Class IV, weighted averages of coking coal and PCI coal

(FY)		2008	2009	2010	2011	2012	Mean
Coking coal	a	1622.8	1532.6	1658.6	1567.2	1551.5	1586.5
PCI coal	b	273.7	243.2	328.4	357.8	389.6	318.5
(a/(a+b))		0.856	0.863	0.835	0.814	0.799	0.833

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
28.79	29.12 / 28.46	28.79	**24.53**	24.73 / 24.33

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
26.52	*26.85 / 26.19*	*26.52*	*26.63*	*26.84 / 26.42*

CI: confidence interval

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
29.00	28.79	-0.007	Within 95% CI	24.51	24.53	+0.001	Within 95% CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI

(No applicable values in the 2006 IPCC Guidelines)

(5) Judgments and conclusions

- The new calculated values have greater validity than the current standard values. The standard values should be updated to the new values.
- Rather than keeping the values fixed in the future, it will probably be appropriate to recalculate the calorific values and carbon emission factors annually in accordance with proportions of consumption of the different steel making coals.

3-1-2. Coking coal

(1) Calculation method and sample sources

Sample sources:	Measurements provided by the Japan Iron and Steel Federation (JISF)
Calculation method:	Class II, direct measurement of heat or the like, with the cooperation of JISF
Measurement method:	Gross (higher) calorific value (moisture free) measured at respective steelworks under JIS M8814[*15] Composition analysis values (carbon contents) measured at respective steelworks under JIS M8813
Correction processing:	Total moisture 11.1% (moisture free) corrected to wet coal (with moisture and ash) [*16] Net (lower) calorific value estimated for total moisture 11.1%, hydrogen 11.1% (moisture free)

(2) Outline of composition analysis, physical properties and measurements

	Gross (higher) calorific value		Carbon contents
	GCV MJ/kg (moisture free)	MJ/kg (wet coal)	(moisture free)
No. of samples used	23	23	23
Maximum	33.55	30.20	0.826
Minimum	30.00	27.00	0.728
Arithmetic mean	32.16	28.94	0.786
Standard deviation	0.821	0.739	0.026

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
28.94	29.26 / 28.62	28.94	**24.42**	24.60 / 24.25

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
26.68	*27.00 / 26.36*	*26.68*	*26.50*	*26.69 / 26.31*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
29.10	28.94	-0.005	Within 95%CI	24.51	24.42	-0.004	Within 95%CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
28.18	*26.68*	*-0.053*	*Within IPCC 95% CI*	*25.80*	*26.50*	*+0.027*	Within IPCC 95% CI
			Outside new calculation 95% CI				*Outside new calculation 95% CI*

(5) Judgments and conclusions

- The new calculated values have greater validity in general than the current standard values. The standard values should be updated to the new values.

[*15] In measurement methods and sampling methods for the current survey by ANRE/METI and GEB/MOE all measurements are conducted to conform with public standards such as Japanese Industrial Standards (JIS). Details of the standards relating to the measurement methods and sampling methods are collectively described in reference 9, which should be referred to as appropriate.

[*16] See Addendum 3 for measurement standards for moisture free coal, dry coal, wet coal, etc.

3-1-3. Pulverized coal injection (PCI) coal

(1) Calculation method and sample sources

Sample sources:	Measurements provided by JISF
Calculation method:	Class II, direct measurement of heat or the like, with the cooperation of JISF
Measurement method:	Gross (higher) calorific value (moisture free) measured at respective steelworks under JIS M8814 Composition analysis values (carbon contents) measured at respective steelworks under JIS M8813
Correction processing:	Total moisture 11.1% (moisture free) corrected to wet coal (with moisture and ash) Net (lower) calorific value estimated for total moisture 11.1%, hydrogen 11.1% (moisture free)

(2) Outline of composition analysis, physical properties and measurements

	Gross (higher) calorific value GCV MJ/kg (moisture free)	MJ/kg (wet coal)	Carbon contents (moisture free)
No. of samples used	20	20	20
Maximum	32.62	29.36	0.830
Minimum	29.54	26.59	0.718
Arithmetic mean	31.12	28.01	0.780
Standard deviation	0.916	0.824	0.037

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
28.01	28.39 / 27.62	28.01	**25.06**	25.35 / 24.76

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
25.74	*26.13 / 25.35*	*25.74*	*27.27*	*27.57 / 26.96*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
28.20	28.01	-0.007	Within 95% CI	24.51	25.06	+0.022	Outside 95% CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
25.82	*25.74*	*-0.003*	*Within IPCC 95% CI*	*25.80*	*27.27*	*+0.016*	*Within IPCC 95% CI*
			Within new calculation 95% CI				*Outside new calculation 95% CI*

Note: The IPCC reference value is the "*Other Bituminous Coal" value.*

(5) Judgments and conclusions

- The current carbon emission factors were inferred from values for coking coal; it is very likely that the current values are not valid.
- The new calculated values have greater validity in general than the current standard calorific values and the 2006 IPCC Guidelines values. The standard values should be updated to the new values.

3-1-4. Imported steam coal

(1) Calculation method and sample sources

Sample sources:	Measurements provided by the Federation of Electric Power Companies of Japan (FEPC)
Calculation method:	Class II, direct measurement of heat or the like, with the cooperation of FEPC
Measurement method:	Gross (higher) calorific value (dry coal and moisture free), measurements by electric power companies, JIS M8814 Composition analysis values (fixed carbon, volatile content, total moisture, ash, carbon, hydrogen, sulfur, etc.) measurements by electric power companies, JIS M8812,13,19
Correction processing:	Moisture free values corrected to wet coal (with moisture and ash) standard by total moisture content; dry coal values corrected to wet coal standard by free water Calorific values and carbon emission factors are both calculated by weighted averages of consumption amounts of sample coals

(2) Outline of composition analysis, physical properties and measurements

	Gross (higher) calorific value GCV MJ/kg(dry coal)	Carbon (dry)	hydrogen (dry)	Sulfur (dry)	Nitrogen (dry)
No. of samples used	721	721	721	721	721
Maximum	31.41	84.59	6.90	2.53	2.36
Minimum	21.15	60.90	3.34	0.00	0.63
Arithmetic mean	27.63	71.60	4.76	0.45	1.47
Standard deviation	1.649	2.264	0.46	0.22	0.28

	Fixed carbon (dry coal)	Volatiles (dry coal)	Ash (dry coal)	Total moisture (dry coal)	Free water (dry coal)
No. of samples used	704	711	721	721	721
Maximum	64.80	54.50	17.10	37.95	23.40
Minimum	36.00	23.00	2.70	6.50	2.80
Arithmetic mean	51.50	36.00	10.55	13.71	7.661
Standard deviation	5.181	6.755	3.704	5.817	2.872

Note: Calorific values for the dry coal standard; composition analysis and physical values are proportions by mass; total moisture is the sum of equilibrium moisture and free water.

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
25.97	26.10 / 25.83	25.97	**24.42**	24.46 / 24.38

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
24.66	*24.80 / 24.52*	*24.66*	*25.68*	*25.74 / 25.63*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
25.70	25.97	+0.010	Outside 95% CI	24.71	24.42	-0.012	Outside 95% CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
25.82	*24.66*	*-0.045*	*Within IPCC 95% CI*	*25.80*	*25.68*	*-0.005*	*Within IPCC 95% CI*
			Outside new calculation 95% CI				*Outside new calculation 95% CI*

(5) Judgments and conclusions

- Although the current standard values fall outside the 95% confidence interval of the new calculated values, the calculation accuracy of the new calculated values is very high and the confidence interval is narrow. The standard conditions have been changed to SATP. The gross (higher) calorific value and carbon emission factor are both within a range of about ±1% of the current standard values. Taken together, these facts indicate that the new calculated values are strongly valid. The standard values should probably be updated to the new calculated values.
- Comparing the new calculated values with the 2006 IPCC Guidelines, because the IPCC's calorific values also employ the dry coal standard, the new calorific values and carbon emission factors are generally valid.

(6) Results of regression analysis for interpolation and approximation expressions (values in parentheses are p-values)

- Highly accurate expressions for estimating calorific values were found from the results of the regression analysis for interpolation and approximation expressions.
- Equations with some degree of accuracy for estimating the carbon emission factors were found. The estimation accuracy for the carbon emission factor based on the net (lower) calorific value is higher than that based on the gross (higher) calorific value.

$$GCV = 0.0457*C + -0.0254*V + -0.3339*W + -0.2057*A + 0.8246*S + 30.7137$$
(0.000) (0.013) (0.000) (0.000) (0.000) (0.000)
n= 699, R^2= 0.9038, AIC= 1109.525, with the correction of heteroskedasticity (Equation3-1-4-1

$$CEF\text{-}G = 0.0394*C + -0.0100*V + 0.0777*W + 0.0217*A + -0.2612*S + 21.6706$$
(0.000) (0.199)x (0.000) (0.046) (0.001) (0.000)
n= 699, R^2= 0.5200, AIC= 547.400, with the correction of heteroskedasticity (Equation3-1-4-2

$$CEF\text{-}G = -0.4178*GCV + 0.0585*C + -0.0206*V + -0.0618*W + -0.0643*A$$
(0.000) (0.000) (0.000) (0.008) (0.000)
$$+ 0.0834*S + 34.5029$$
n= 699, R^2= 0.7073, AIC= 203.7489, with the correction of heteroskedasticity
(0.156)x (0.000) (Equation 3-1-4-3

$$NCV = 0.0555*C + -0.0281*V + -0.3469*W + -0.1930*A + 0.7601*S + 29.1109$$
(0.000) (0.006) (0.000) (0.000) (0.000) (0.000)
n= 698, R^2= 0.9223, AIC= 1052.013, with the correction of heteroskedasticity (Equation 3-1-4-4

$$CEF\text{-}N = 0.0273*C + -0.0076*V + 0.1203*W +0.0224*A + -0.2711*S + 22.9118$$
(0.000) (0.158)x (0.000) (0.012) (0.001) (0.000)
n= 698, R^2= 0.6876, Adj-R^2= 0.6853, AIC= 668.6036 (Equation 3-1-4-5

$$CEF\text{-}N = -0.4712*NCV + 0.0535*C + -0.0209*V + -0.0432*W + -0.0685*A$$
(0.000) (0.000) (0.000) (0.008) (0.000)
$$+0.0870*S + 36.6283$$
n= 698, R^2= 0.8077, Adj-R^2= 0.8060, AIC= 331.815
(0.175)x (0.000) (Equation 3-1-4-6

$$NCV = 1.0667*GCV + -2.9884$$
n= 698, R^2= 0.9960, Adj-R^2= 0.9960, AIC=-1024.158
(0.000) (0.000) (Equation 3-1-4-7

$$CEF\text{-}N = 1.2584*CEF\text{-}G - 5.0498$$
n= 698, R^2= 0.8668, AIC= 65.56, with the correction of heteroskedasticity
(0.000) (0.000) (Equation 3-1-4-8

GCV	Gross (higher) calorific value		MJ/kg	NCV	Net (lower) calorific value		MJ/kg
CEF-G	Carbon emission factors (gross (higher))		gC/MJ	CEF-N	Carbon emission factors (net (lower))		gC/MJ
C	Fixed carbon	(dry coal basis)	wt%	V	Volatile content	(dry coal basis)	wt%
W	Total moisture	(dry coal basis)	wt%	A	Ash content	(dry coal basis)	wt%
S	Sulfur content	(dry coal basis)	wt%				

See the attached figures: Figs. 3-1-4-1 to 3-1-4-4. Correlations of calorific values vs carbon emission factors for imported steam coal, etc.

3-1-5. Imported anthracite (hard coal)

(1) Calculation method and sample sources

Sample sources:	Assumed typical composition and physical values of anthracite taken from the definitions of types of coal
Calculation method:	Class IV, values estimated using interpolation and approximation expressions from imported steam coal The typical composition and physical values listed below are substituted into equations 3-1-4-1, -2, -4 and -5. The 95% confidence interval of the estimated values is estimated from the 95% confidence intervals of the independent variables of the interpolation and approximation expressions.

(2) Outline of composition analysis, physical properties and measurements

Generally, anthracite has a fuel ratio at least 4[*17] and the volatile content under the dry and ash free standard is less than 10%. Accordingly, the typical composition and physical values of anthracite listed below are assumed.

wt%	Anthracite	(References: see section 3-1-4. Imported steam coal)
Fixed carbon	80.00	51.50
Volatiles	7.50	36.00
Total moisture	13.71	13.71
Ash	10.55	10.55
Sulfur	0.45	0.45

Note: Composition analysis and physical values for the dry coal standard; total moisture is the sum of equilibrium moisture and free water.

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
27.80	29.05 / 26.55	27.80	**25.92**	26.76 / 25.09

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
26.89	*28.09 / 25.68*	*26.89*	*26.80*	*29.41 / 24.52*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
26.90	27.80	+0.034	Within 95%CI	25.46	25.92	+0.018	Within 95%CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
26.68	*26.89*	*+0.008*	*Within IPCC 95% CI*	*26.80*	*26.80*	*+0.000*	*Within IPCC 95% CI*
			Within new calculation 95% CI				*Within new calculation 95% CI*

(5) Judgments and conclusions

- Although the values are estimated by interpolation and approximation expressions from steam coal and the typical chemical composition and physical characteristics, these results are particularly satisfactory in very closely matching the calorific values and carbon emission factors in the 2006 IPCC Guidelines. Therefore, the standard values should be updated to the new calculated values.

[*17] The fuel ratio is the ratio between fixed carbon and volatile contents. See Table 2 of reference 9, JIS M1002 (calculation of coal reserves), for the definition of anthracite.

3-1-6. Indigenous produced steam coal (reference values)

(1) Calculation method and sample sources (As in 3-1-4. Imported steam coal, cooperation provided by FEPC)

(2) Outline of composition analysis, physical properties and measurements

	Gross (higher) calorific value GCV MJ/kg (dry coal)	Carbon (dry)	Hydrogen (dry)	Sulfur (dry)	Nitrogen (dry)
No. of samples used	12	12	12	12	12
Maximum	27.10	67.90	5.67	0.25	1.06
Minimum	26.39	66.30	5.29	0.23	0.99
Arithmetic mean	26.79	67.12	5.55	0.24	1.02
Standard deviation	0.224	0.613	0.11	0.01	0.02

	Fixed carbon (dry coal)	Volatiles (dry coal)	Ash (dry coal)	Total moisture (dry coal)	Free water (dry coal)
No. of samples used	12	12	12	12	12
Maximum	40.60	47.40	15.10	13.20	7.60
Minimum	37.90	45.60	12.90	10.60	5.30
Arithmetic mean	39.08	46.78	14.15	11.90	6.39
Standard deviation	0.826	0.567	0.722	0.916	0.777

Note: Calorific values for the dry coal standard; composition analysis and physical values are proportions by weight; total moisture is the sum of equilibrium moisture and free water.

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
25.28	25.48 / 25.09	25.28	**23.74**	23.80 / 23.68

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
23.90	*24.09 / 23.71*	*23.90*	*25.12*	*25.19 / 25.05*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
22.50	25.28	+0.124	Outside 95%CI	24.90	23.74	-0.047	Outside 95%CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
25.82	*23.90*	*-0.075*	*Within IPCC 95% CI* *Outside new calculation 95% CI*	*25.80*	*25.12*	*-0.026*	*Within IPCC 95% CI* *Outside new calculation 95% CI*

(5) Judgments and conclusions

- The current standard values for indigenous produced steam coal are values from before FY2000, when large mines were operating, and are probably no longer valid. Therefore, the standard values should be updated to the new calculated values.
- Indigenous produced steam coal currently accounts for no more than 0.7% of the consumption of steam coal for power generation use; only 12 samples were obtained. Therefore, it is appropriate to use reference values instead.
- For similar reasons, it is appropriate to eliminate the categories of underground indigenous steam coal and open pit indigenous steam coal from the current standard values.

3-1-7. Lignite or brown coal (reference values)

(1) Calculation method and sample sources

Sample sources:	Assumed typical composition and physical values of lignite or brown coal taken from a literature survey
Calculation method:	Class IV, values estimated using interpolation and approximation expressions from imported steam coal The typical composition and physical values listed below are substituted into equations 3-1-4-1, -2, -4 and -5. The 95% confidence interval of the estimated values is estimated from the 95% confidence intervals of the independent variables of the interpolation and approximation expressions.

(2) Outline of composition analysis, physical properties and measurements

The assumed typical composition and physical properties of lignite or brown coal listed below are taken from the composition and physical properties of brown coal produced in Victoria State, Australia[*18].

wt%	Lignite or brown coal	(References: see sections 3-1-4. Imported steam coal and 3-1-5. Anthracite)	
Fixed carbon	38.00	51.50	80.00
Volatiles	50.00	36.00	7.50
Total moisture	54.00	13.71	13.71
Ash	1.70	10.55	10.55
Sulfur	0.30	0.45	0.45

Note: Composition analysis and physical values for the dry coal standard; total moisture is the sum of equilibrium moisture and free water.

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
13.05	14.32 / 11.78	13.05	**26.82**	27.67 / 25.97

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
10.98	*12.20 / 9.76*	*10.98*	*30.02*	*32.65 / 27.72*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
17.20	13.75	-0.241	Outside 95%CI	24.71	26.82	+0.085	Outside 95%CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
11.93	*10.98*	*-0.080*	*Within IPCC 95% CI*	*27.60*	*30.02*	*+0.088*	*Within IPCC 95% CI*
			Within new calculation 95% CI				*Outside new calculation 95% CI*

(5) Judgments and conclusions

- The current standard values are values for brown coal (lignite), which is no longer used in Japan, and the carbon emission factors are analogous values taken from imported steam coal. It is very likely that the current standard values are not valid.
- Although the values are estimated by interpolation and approximation expressions from steam coal and the typical chemical composition and physical characteristics, the obtained results are valid, particularly from a comparison with the 2006 IPCC Guidelines. Therefore, the standard values should be updated to the new calculated values.
- The name of this category should be changed from "lignite" to "lignite or brown coal".

[*18] For sources of the values, see reference 11, A. Chaffee (2005).

3-2. Coal products

3-2-1. Coke

(1) Calculation method and sample sources

Sample sources: Measurements provided by JISF

Calculation method:	Class II, direct measurement of heat or the like, with the cooperation of JISF
Measurement method:	Gross (higher) calorific value (wet coal and dry coal) measured at respective steelworks under JIS M8814 Composition analysis values (carbon contents) measured at respective steelworks under JIS M8813

Correction processing: (not applicable)

(2) Outline of composition analysis, physical properties and measurements

	Gross (higher) calorific value		Carbon contents
	GCV MJ/kg (dry coal)	MJ/kg (wet coal)	(dry coal)
No. of samples used	12	12	12
Maximum	29.42	29.40	0.890
Minimum	28.72	28.72	0.870
Arithmetic mean	29.18	29.18	0.882
Standard deviation	0.195	0.193	0.008

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
29.18	29.30 / 29.06	29.18	**30.22**	30.45 / 29.99

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
28.81	*28.95 / 28.67*	*28.81*	*30.60*	*30.76 / 30.45*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
29.40	29.18	-0.007	Outside 95%CI	29.38	30.22	+0.028	Outside 95%CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
28.20	*28.81*	*+0.008*	*Within IPCC 95% CI*	*29.50*	*30.60*	*+0.037*	*Within IPCC 95% CI*
		Outside new calculation 95% CI				*Outside new calculation 95% CI*	

(5) Judgments and conclusions

- Although the current standard values fall outside the 95% confidence intervals of the new calculated values, the calculation accuracy of the new calculated values is very high and the confidence intervals are very narrow. The new calculated values themselves are less than 3% larger or smaller than the current values. The standard values of both the calorific values and the carbon emission factors should be updated to the new calculated values.

3-2-2. Coke oven gas

(1) Calculation method and sample sources

Sample sources:	Measurements provided by JISF
Calculation method:	Class II, Weighted averaging of pure components with the cooperation of JISF
Measurement method:	Composition analysis values measured at respective steelworks under JIS M8812
Correction processing:	(not applicable)

(2) Outline of composition analysis, physical properties and measurements

(mol %)	Hydrogen	Methane	Carbon monoxide	Ethylene
No. of samples used	24	24	24	24
Maximum	57.80	29.70	7.60	2.90
Minimum	54.70	24.52	6.10	0.00
Arithmetic mean	56.04	26.92	6.76	1.93
Standard deviation	0.863	1.759	0.52	1.15

(mol %)	Carbon dioxide	Ethane	Propylene	Propane
No. of samples used	24	24	24	24
Maximum	2.60	2.50	0.17	0.04
Minimum	1.60	0.70	0.00	0.00
Arithmetic mean	2.24	1.23	0.10	0.02
Standard deviation	0.30	0.71	0.06	0.02

Note: There are also impurity gases such as nitrogen.

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/m^{3}SATP	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
19.12	19.44 / 18.80	44.39	**10.93**	11.01 / 10.85

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/m^{3}SATP	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
15.21	*15.48 / 14.93*	*35.30*	*13.74*	*13.83 / 13.66*

(4) Comparison with current standard values and verification (Note: The current standard calorific values are corrected to SATP.)

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
19.33	19.12	-0.011	Within 95%CI	10.99	10.93	-0.006	Within 95%CI
19.01	19.12	+0.006	Within 95%CI (Actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
38.66	*35.30*	*-0.087*	*Within IPCC 95% CI*	*12.09*	*13.74*	*+0.136*	*Within IPCC 95% CI*
		Outside new calculation 95%CI				*Outside new calculation 95%CI*	

Note: The confidence intervals for coke oven gas in the 2006 IPCC Guidelines are estimates; care is required.

(5) Judgments and conclusions

- The new calculated values broadly have greater validity than the current standard values corrected to SATP. The standard values should be updated to the new calculated values.
- Compared with the 2006 IPCC Guidelines, the calorific values are smaller but the carbon emission factors are larger. Observed causes of this divergence include the fact that the 2006 IPCC Guidelines values are estimates from typical analyses of coke oven gas based on a literature survey around 2005 and the confidence intervals are also estimates, and the fact that the standard conditions were probably different.

3-2-3. Blast furnace gas

(1) Calculation method and sample sources

Sample sources:	Measurements provided by JISF
Calculation method:	Class II, Weighted averaging of pure components with the cooperation of JISF
Measurement method:	Composition analysis values measured at respective steelworks under JIS M8812
Correction processing:	Excluding carbon dioxide (CO_2) from the calculation of carbon emission factors (the combustible carbon method[*19])

(2) Outline of composition analysis, physical properties and measurements

(mol %)	Nitrogen	Carbon monoxide	Carbon dioxide (excluded)	Hydrogen
No. of samples used	30	30	30	30
Maximum	51.50	25.95	24.20	5.15
Minimum	46.70	21.58	20.10	3.85
Arithmetic mean	48.98	23.86	22.68	4.49
Standard deviation	1.428	1.239	1.007	0.31

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/m^{3}SATP	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
3.284	3.34 / 3.23	2.64	**35.65**	35.85 / 35.46

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/m^{3}SATP	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
3.13	*2.56 / 2.47*	*2.52*	*37.35*	*37.50 / 37.20*

(4) Comparison with current standard values and verification (Note: The current standard calorific values are corrected to SATP.)

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
3.12	3.28	+0.051	Outside 95%CI	26.13	35.65	+0.364	Outside 95%CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
Kainou ('05)	New calculation	Change	95% CI	Kainou ('05)	New calculation	Change	95% CI
2.47	*2.52*	*+0.018*	*(no IPCC intervals)*	*37.40*	*37.35*	*-0.001*	*(no IPCC intervals)*
		Outside new calculation 95% CI				*Within new calculation 95% CI*	

Note: The comparison is with values according to the combustible carbon method in Kainou (2005), reference 7, rather than the 2006 IPCC Guidelines. There is no information on confidence intervals for blast furnace gas in Kainou (2005).

(5) Judgments and conclusions

- The current standard values of calorific values are estimates from actual values in Electric Power Statistics. The current standard values of carbon emission factors are based on allocation calculations from energy balances of blast furnaces and are also estimates.
- The new calculated values are very reliable, with narrow confidence intervals; differences from the current standard values can be considered to be due to differences in standard conditions. The calorific values should be updated to the new calculated values.
- However, as in the past, the carbon emission factors of blast furnace gas should be determined as carbon emissions contributions in the areas of consumption of blast furnace gas, such as steelmaking, ironmaking and electric power generation, by the energy consumption allocation

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[*19] The combustible carbon method is a method for calculating carbon emission factors that excludes the carbon dioxide in blast furnace gas and converter furnace gas. The 2006 IPCC Guidelines used the total carbon method, a calculation method that does not exclude carbon dioxide. See Addendum 4 for the application of these calculation methods and, for blast furnace gas, the energy consumption allocation method.

method.

3-2-4. Converter furnace gas; galvanic furnace gas (reference values)

(1) Calculation method and sample sources

Sample sources:	Measurements provided by JISF
Calculation method:	Class II, Weighted averaging of pure components with the cooperation of JISF
Measurement method:	Composition analysis values measured at respective steelworks under JIS M8812
Correction processing:	Excluding carbon dioxide (CO_2) from the calculation of carbon emission factors (the combustible carbon method)

(2) Outline of composition analysis, physical properties and measurements

(mol %)	Carbon monoxide	Carbon dioxide (excluded)	Nitrogen	Hydrogen
No. of samples used	30	30	30	30
Maximum	69.38	20.49	25.63	2.50
Minimum	58.94	12.00	11.00	0.09
Arithmetic mean	64.92	15.87	18.10	1.12
Standard deviation	3.162	2.615	4.085	0.80

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/m^{3}SATP	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
7.640	7.78 / 7.50	6.18	**41.72**	41.92 / 41.52

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/m^{3}SATP	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
7.603	*7.74 / 7.47*	*6.15*	*41.92*	*42.06 / 41.77*

(4) Comparison with current standard values and verification (Note: The current standard calorific values are corrected to SATP.)

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
7.70	7.64	-0.008	Within 95%CI	38.44	41.72	+0.085	Outside 95% CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
Kainou ('05)	New calculation	Change	95% CI	Kainou ('05)	New calculation	Change	95% CI
7.06	*6.15*	*-0.129*	*(no IPCC intervals)*	*40.70*	*41.92*	*+0.030*	*(no IPCC intervals)*
		Outside new calculation 95% CI				*Outside new calculation 95% CI*	

Note) The comparison is with values according to the combustible carbon method in Kainou (2005), reference 7, rather than the 2006 IPCC Guidelines. There is no information on confidence intervals for converter furnace gas in Kainou (2005).

(5) Judgments and conclusions

- The current standard values of calorific values are actual values from JISF in FY1998 and the current standard values of carbon emission factors are values in the 2006 IPCC Guidelines that have been converted to the combustible carbon method. It is very likely that they are all no longer valid.
- The calculation accuracy of the new calculated values is very high and the confidence intervals are very narrow. Therefore, the calorific values should be updated to the new calculated values and the carbon emission factors should be updated to the new calorific values in accordance with the combustible carbon method as in the past[*20].
- It is probably valid to apply the standard calorific values and carbon emission factors for converter furnace gas to galvanic furnace gas, which has similar characteristics, and to introduce galvanic furnace gas as a new entry for reference.

[*20] See Addendum 4 for the application of the combustible carbon effort to converter furnace gas.

3-2-5. Coal tar (reference values)

(1) Calculation method and sample sources

Sample sources:	Calorific values: standard values (specified in METI's Current Survey of Energy Consumption) Carbon emission factors: standard values (values converted from the 2006 IPCC Guidelines)
Calculation method:	Class V, keeping current standard values

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results (not applicable)

(4) Comparison with current standard values and verification (not applicable)

(5) Judgments and conclusions

- As in the current standard values, a gross (higher) calorific value of 37.3 MJ/kg and a corresponding carbon emission factor of 20.9 gC/MJ can be used.
- When necessary, the net (lower) calorific value of 28.0 MJ/kg and corresponding carbon emission factor of 22.0 gC/MJ from the 2006 IPCC Guidelines can be used.

3-2-6. Coal briquette (reference values)

(1) Calculation method and sample sources

Sample sources:	Calorific values: Current standard values (legacy values from before the FY2000 revision) Carbon emission factors: carbon emission factors of imported anthracite (see section 3-1-6.)
Calculation method:	Class V, keeping the current standard values for the calorific values and updating the carbon emission factors to the values for imported anthracite

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results

Gross (higher) calorific value:	23.90 MJ/kg,
Carbon emission factors (gross (higher)):	25.92 gC/MJ

(4) Comparison with current standard values and verification (not applicable)

(5) Judgments and conclusions

- Coal briquettes are produced by pulverizing a coal such as anthracite, adding slaked lime and small quantities of firelighter and binder, and molding into the briquette shape.
- The current standard value of the gross (higher) calorific value is a legacy value from before the FY2000 revision (then 5700 kcal/kg), which corresponds to the calorific value of anthracite containing about 15% impurities such as ash.
- In the current revision, a gross (higher) calorific value of 23.9 MJ/kg as in the current standard values and a corresponding carbon emission factor of 25.9 gC/MJ, the value for imported anthracite[*21], can be used.
- When necessary, based on the ratio between the gross (higher) calorific value and net (lower) calorific value of imported anthracite, a net (lower) calorific value of 23.1 MJ/kg can be used. The value for imported anthracite, 26.8 gC/MJ, can be used for the corresponding carbon emission factor.

[*21] In the current standard values, the carbon emission factors of coke are used for coal briquettes. This is the result of an error on my part and the factors are about 12% too large. I wish to correct this now and offer my humble apologies to all concerned.

3-2-7. Coal oil mixture (COM); coal water mixture (CWM) (reference values)

(1) Calculation method and sample sources

Sample sources: Calorific values: current standard values for both COM and CWM (legacy values from the FY2005 revision)
Carbon emission factors:
COM: carbon emission factor calculated from proportions of imported steam coal and fuel oil C
CWM: carbon emission factor of imported steam coal (see section 3-1-4.)

Calculation method: Class IV, calorific values keeping the current standard values; carbon emission factors updated to calculated values based on imported steam coal and fuel oil C

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results

	Gross (higher) calorific value	Carbon emission factor (gross (higher))
COM	36.20 MJ/kg	21.88 gC/MJ
CWM	20.90 MJ/kg	24.42 gC/MJ

(4) Comparison with current standard values and verification (not applicable)

(5) Judgments and conclusions

- COM is a mixture of coal and fuel oil and CWM is a mixture of coal and water. Both are used as fuels for electricity generation and boiler use.
- The current standard values of the gross (higher) calorific values are legacy values from before the 2000 revision; they are actual values from when COM and CWM were actually used in power generation equipment by electric power companies.
- Because COM and CWM have not been used in Japan in recent years, the current standard values of the calorific values can continue to be used. The carbon emission factors can be updated by calculation from the calorific values and carbon emission factors of imported steam coal and fuel oil C.
- To be specific, given the calorific values, COM can be treated as a mixture of 40.1% by mass imported steam coal and 59.9% fuel oil C. Accordingly, the carbon emission factors are calculated by weighted averaging of this mixture ratio. Assuming CWM is a mixture of imported steam coal and water, the carbon emission factors can be updated to the values for imported steam coal.

4. Results (2) Oil and Oil Products

4-1. Crude oil and natural gas liquid (NGL)/condensate

4-1-1. Crude oil for refinery use

(1) Calculation method and sample sources

Sample sources:	Measurements in a survey commissioned by ANRE/METI and GEB/MOE, based on measurement samples obtained with the cooperation of Petroleum Association of Japan (PAJ)
Calculation method:	Class III, direct measurement of heat, etc. in the survey commissioned by ANRE/METI and GEB/MOE
Measurement method:	Gross (higher) calorific value measured by the contractor under JIS K2279 (measurements) Chemical composition and physical properties: density, sulfur content, ash content and water content measured by the contractor under JIS K2249, 41, 72, 75; carbon content and hydrogen content measured by the contractor under ASTM-D5291
Correction processing:	Gross (higher) calorific value corrected for sulfur content (measured value-0.586*S*D)

(2) Outline of composition analysis, physical properties and measurements

	GCV MJ/l (corrected)	Density D	Sulfur Swt%	Ash Awt%	Water Wwt%	Carbon Cwt%	Hydrogen Hwt%
No. of samples used	163	163	163	163	163	163	163
Maximum	40.31	0.940	3.78	0.07	0.70	87.00	14.70
Minimum	36.16	0.780	0.02	0.00	0.00	83.00	11.10
Arithmetic mean	38.28	0.853	1.57	0.01	0.03	85.34	13.04
Standard deviation	0.749	0.028	0.90	0.01	0.08	0.789	0.712

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
38.28	38.40 / 38.17	44.92	**19.00**	19.04 / 18.96

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
36.04	*36.16 / 35.92*	*42.30*	*20.18*	*20.22 / 20.14*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
38.20	38.28	+0.002	Within 95%CI	18.66	19.00	+0.018	Outside 95%CI
38.12	38.28	+0.004	Outside (actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
42.35	*42.30*	*-0.001*	*Within IPCC 95% CI*	*20.00*	*20.18*	*+0.009*	*Within IPCC 95% CI*
			Within new calculation 95% CI				*Outside new calculation 95% CI*

(5) Judgments and conclusions

- Although the current actual calorific values fall outside the 95% confidence intervals of the new calculated values, the calculation accuracy of the new calculated values is high and the confidence interval is narrow. The gross (higher) calorific value and carbon emission factor are within a range of about ±2% of the current standard values. In particular, the gross (higher) calorific value and carbon emission factor almost match the values in the 2006 IPCC Guidelines and the respective values are within one another's 95% confidence intervals. Taken together, these facts indicate that the new calculated values are strongly valid. The standard values should probably be updated to the new calculated values.

- There is a very wide range of oils, from kerosene to fuel oil C, reflecting differences in the properties and qualities of crude oils. Rather than using a single carbon emission factor for all crude oil as at present, I think it will be appropriate to shift to a method of using the interpolation and approximation equations below to estimate respective carbon emission factors of crude oils by grade and by brand and aggregating the estimated values, and to shift to a method of estimating accurate carbon balances that reflect year-by-year variations in the grades and brands of imported crude oil.

(6) Results of regression analysis for interpolation and approximation equations (values in parentheses are p-values; samples include NGL/condensate)

- The results of regression analysis for interpolation and approximation equations revealed accurate estimation equations for both the gross (higher) and net (lower) calorific values. In particular, a more accurate estimation equation (equation 4-1-1-1) for estimating the gross (higher) calorific value than the current equations in JIS K2279 has been identified.
- Accurate estimation equations for both the gross (higher) and net (lower) carbon emission factors were also found. It is apparent that the estimation equation for the gross (higher) factor is more accurate in general than the estimation equation for the net (lower) factor.

$\text{GCV-V} = -23.0196{*}D^2 + 73.7305{*}D + -0.2740{*}S + -7.4694{*}A + -0.2384{*}W \; -7.3339$
(0.010) (0.000) (0.000) (0.175) (0.248)x (0.190)x
n=184, $\underline{R^2 = 0.9815}$, Adj-R^2= 0.9810, AIC= -107.8968 (Equation 4-1-1-1

JIS K2279 estimation equation (for reference): $\text{GCV-V}=[(51.916-8.792{*}D^2){*}(1-0.01{*}(A+W+S))+0.09420S){*}D$
n=184, R^2= 0.9794

$D = 0.0257{*}\text{GCV-V} + 0.0095{*}S + 0.3732{*}A + 0.0096{*}W + -0.1492$
(0.000) (0.000) (0.000) (0.080)x (0.000)
n=184, $\underline{R^2 = 0.9877}$, Adj-R^2= 0.9875, AIC= -1442.303 (Equation 4-1-1-2

$\text{GCV-W} = -7.1261{*}D^2 + -0.3223{*}S + -8.4194{*}A + -0.2690{*}W + 50.6860$
(0.000) (0.000) (0.000) (0.146)x (0.000)
n=184, $\underline{R^2 = 0.9229}$, AIC= -42.24358, with the correction of heteroskedasticity (Equation 4-1-1-3

$\text{CEF-G} = 3.9931{*}D^2 + 4.1492{*}A + 16.0591$
(0.000) (0.006) (0.000)
n=184, R^2= 0.7863, Adj-R^2= 0.7840, AIC= -150.0491 (Equation 4-1-1-4

$\text{CEF-G} = -0.4490{*}\text{GCV-V} + 35.4841{*}D + -7.3198{*}D^2 + -0.1627{*}S + 11.5173$
(0.000) (0.000) (0.141)x (0.000) (0.000)
n=184, R^2= 0.8433, Adj-R^2= 0.8398, AIC= -203.0771 (Equation 4-1-1-5

$\text{CEF-G} = -0.5303{*}\text{GCV-W} + -0.1758{*}S + 43.0913$
(0.000) (0.000) (0.000)
n=184, R^2= 0.8289, Adj-R^2= 0.8270, AIC= -190.9302 (Equation 4-1-1-6

$\text{NCV-V} = 64.3577{*}D^{0.5} + -0.2611{*}S + -9.6032{*}A + -22.8929$
(0.000) (0.000) (0.000) (0.000)
n=184, $\underline{R^2 = 0.9734}$, Adj-R^2= 0.9729, AIC= -46.89336 (Equation 4-1-1-7

$\text{NCV-V} = 0.9921 {*} \text{GCV-V} + -1.9358$
(0.000) (0.000)
n=184, R^2= 0.9949, AIC= -355.1951, with the correction of heteroskedasticity (Equation 4-1-1-8

$\text{NCV-W} = -5.7267{*}D^2 + -0.2887{*}S + -8.7096{*}A + 46.9791$
(0.000) (0.000) (0.001) (0.000)
n=184, R^2= 0.8845, Adj-R^2= 0.8825, AIC= 18.38078 (Equation 4-1-1-9

$\text{NCV-W} = 0.8577 {*} \text{GCV-W} + 3.7570$
(0.000) (0.000)
n=184, $\underline{R^2 = 0.9758}$, Adj-R^2= 0.9757, AIC= -273.616 (Equation 4-1-1-10

$$\text{CEF-N} = 12.2144*D^{0.5} + -0.0388*S + 4.6716*A + 0.0919*W + 8.9272$$

(0.000) (0.043) (0.002) (0.585)x (0.000)

n=184, R^2= 0.7985, Adj-R^2= 0.7940, AIC= -182.9881 (Equation 4-1-1-11

$$\text{CEF-N} = -0.2762*\text{NCV-V} + 30.0430*D^{0.5} + 2.3748*A + -0.1125*S + 2.5568$$

(0.000) (0.000) (0.072)x (0.000) (0.048)

n=184, R^2= 0.8304, Adj-R^2= 0.8266, AIC= -213.0261 (Equation 4-1-1-12

$$\text{CEF-N} = -0.4480*\text{NCV-W} + 3.6919*A + -0.0923*S + 39.2264$$

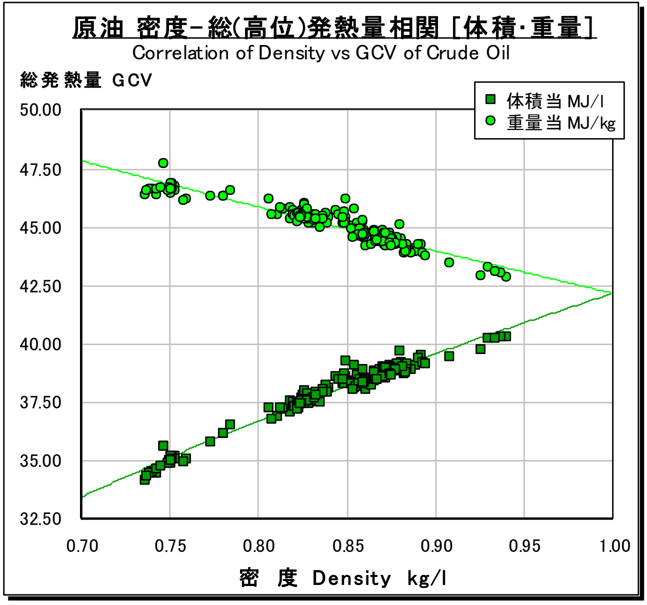
(0.000) (0.016) (0.000) (0.000)

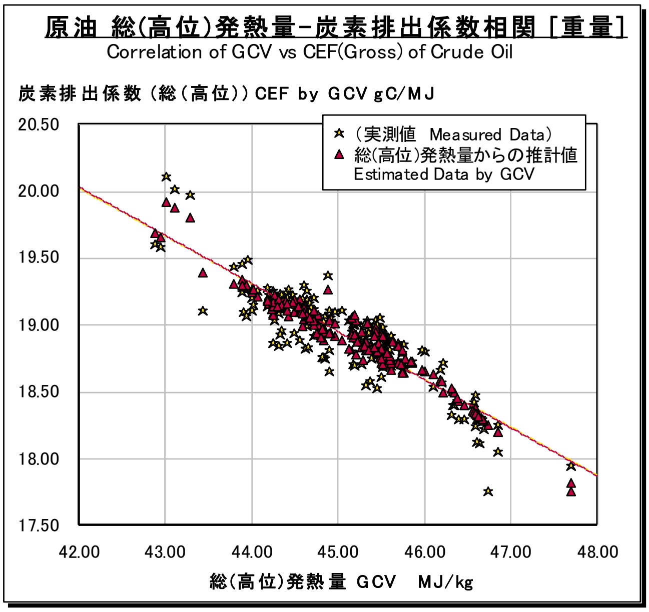
n=184, R^2= 0.7652, Adj-R^2= 0.7613, AIC= -155.1064 (Equation 4-1-1-13

GCV	Gross (higher) calorific value -V MJ/l -W MJ/kg	NCV	Net (lower) calorific value -l MJ/l -W MJ/kg
CEF-G	Carbon emission factor (gross (higher)) gC/MJ	CEF-N	Carbon emission factor (net (lower)) gC/MJ
D	Density --	A	Ash content wt%
W	Water content wt%	S	Sulfur content wt%

See Figs. 4-1-1-1 to 4-1-1-8 of the attached figures for correlations of calorific values vs carbon emission factors of crude oil and of NGL/condensate.

[For reference: Fig. 4-1-1-1. Correlation of density vs gross (higher) calorific value for crude oil; Fig. 4-1-1-7. Correlation of gross (higher) calorific value vs carbon emission factor]





4-1-2. NGL/condensate

(1) Calculation method and sample sources

(As in 4-1-1. Crude oil for refinery use, survey commissioned by ANRE/METI and GEB/MOE)

(2) Outline of composition analysis, physical properties and measurements

	GCV MJ/l (corrected)	Density D	Sulfur Swt%	Ash Awt%	Water Wwt%	Carbon Cwt%	Hydrogen Hwt%
No. of samples used	21	21	21	21	21	21	21
Maximum	35.83	0.774	0.29	0.01	0.05	85.80	15.00
Minimum	34.16	0.737	0.01	0.00	0.00	83.00	13.90
Arithmetic mean	34.93	0.749	0.21	0.00	0.00	85.13	14.50
Standard deviation	0.400	0.008	0.08	0.00	0.01	0.630	0.319

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
34.93	35.11 / 34.74	46.61	**18.26**	18.35 / 18.18

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
32.73	*32.91 / 32.56*	*43.69*	*19.49*	*19.58 / 19.39*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
35.30	34.93	-0.011	Outside 95%CI	18.40	18.26	-0.007	Outside 95%CI
34.80	34.93	+0.004	Within 95%CI (actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
44.15	*43.69*	*-0.011*	*Within IPCC 95% CI*	*17.20*	*19.49*	*+0.133*	*Within IPCC 95% CI*
		Outside new calculation 95% CI				*Outside new calculation 95% CI*	

(5) Judgments and conclusions

- Although the current standard values fall outside the 95% confidence intervals of the new calculated values, the differences are tiny and the results seem to be valid. The standard values should be updated to the new calculated values.
- Comparing the results with the 2006 IPCC Guidelines, the calorific values are almost equal but the new calculated carbon emission factors are 13% larger. Observed causes of this divergence are differences in the standard conditions and the fact that many of the NGL/condensate brands imported into Japan are heavy condensates derived from natural gas, which are different from the light condensates derived from oil.

4-1-3. Crude oil for power generation use (reference values)

(1) Calculation method and sample sources

Sample sources: Estimates from the results of a survey of calorific values of crude oil for power generation use in Electric Power Statistics

Calculation method:

Class IV, estimation using interpolation and approximation equations from crude oil for refinery use

The average gross (higher) calorific value of crude oil for power generation use from FY2012 (39.30 MJ/L) was substituted into equation 4-1-1-2 to find an estimated density (0.8766); this estimated density and gross (higher) calorific value were used in the estimation equations listed below.

- Gross (higher) calorific value by mass Equation 4-1-1-3,
- Carbon emission factor (gross (higher)) Equation 4-1-1-6,
- Net (lower) calorific value by volume Equation 4-1-1-8, by mass Equation 4-1-1-10,
- Carbon emission factor (net (lower)) Equation 4-1-1-13

Ash, water and sulfur contents are assumed to be the same as in crude oil for refinery use. The 95% confidence intervals of the estimated values are estimated from the 95% confidence intervals of the independent variable factors in the interpolation and approximation equations.

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
39.30	**--- / ---**	44.69	**19.14**	21.44 / 16.85

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
37.05	*37.40 / 36.70*	*42.09*	*20.27*	*23.24 / 17.29*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
39.40	39.30	-0.003	Outside 95%CI	18.66	19.14	+0.026	Within 95%CI
39.30	39.30	---	(Identical) (actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
42.35	*42.09*	*-0.006*	*Within IPCC 95% CI*	*20.00*	*20.27*	*+0.013*	*Within IPCC 95% CI*
			Within new calculation 95%CI				*Within new calculation 95%CI*

(5) Judgments and conclusions

- Even though the calorific values and carbon emission factors are estimated using interpolation and approximation equations from crude oil for refinery use and an average gross (higher) calorific value, the results are excellent in closely matching the 2006 IPCC Guidelines. The standard values should be updated to the new calculated values.

4-1-4. Bituminous mixture fuel (reference values)

(1) Calculation method and sample sources

Sample sources:	Calorific value: Current standard value (actual values in FY2005 from Electric Power Statistics) Carbon emission factor: Current standard value (values converted from the 2006 IPCC Guidelines)
Calculation method:	Class V, keeping current standard values

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results (not applicable)

(4) Comparison with current standard values and verification (not applicable)

(5) Judgments and conclusions

- The 2006 IPCC Guidelines values for bituminous mixture fuel are values for fuel from Orimulsion® of Venezuela; the current carbon emission factor (19.96 gC/MJ) was converted from those values.
- Bituminous mixture fuel was in the past used for power generation in Japan by electric power companies and the like. The current standard value of the gross (higher) calorific value (22.44 MJ/kg) is the actual value from 2005.
  For reasons such as Venezuelan government policies restricting production in recent years[*22], this fuel is not currently being used in Japan. Therefore, the current standard value should be kept.
- For the net (lower) calorific value and the corresponding carbon emission factor, when necessary, the values for Orimulsion in the 2006 IPCC Guidelines can be used.

[*22] In the context of rising crude oil prices in recent years, it has become more profitable to add heavy bituminous extracts to light crude to produce medium-gravity crude than to emulsify heavy bituminous oil. Consequently, the Venezuelan government has implemented policies to prioritize production of the former.

4-2. Oil products

4-2-1. Liquefied petroleum gas (LPG)

Pure propane (reference values); pure butane (reference values)

(1) Calculation method and sample sources

Sample sources:	Theoretical calorific values and carbon emission factors of propane and butane Proportional domestic supply amounts of propane and butane from Mineral Resources and Petroleum Products Statistics
Calculation method:	Class I, composition weighted averaging using theoretical values of propane and butane and, from Mineral Resources and Petroleum Products Statistics, proportional domestic supply amounts totalled from indigenous production and imports

(FY, 10^3t)		2008	2009	2010	2011	2012	Mean
Indigenous production	Propane	2373	2382	2238	2102	2200	2259
	Butane	2153	2341	1891	1959	2016	2072
Imports	Propane	9454	8455	9349	9561	10023	9368
	Butane	3787	3235	3155	3298	3307	3356
proportional domestic supply amounts	Propane	0.666	0.660	0.697	0.689	0.697	0.682
	Butane	0.334	0.340	0.303	0.311	0.303	0.318

Correction processing: Proportions of n-butane and i-butane (n-:i-) are assumed to be 50:50.

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
50.06	50.07 / 50.04	50.06	**16.38**	16.39 / 16.37

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
46.43	*46.44 / 46.41*	*46.43*	*17.66*	*17.67 / 17.66*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
50.80	50.06	-0.015	Outside 95%CI	16.32	16.38	+0.004	Outside 95%CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
47.31	*46.43*	*-0.019*	*Within IPCC 95% CI* *Outside new calculation 95%CI*	*17.37*	*17.66*	*+0.017*	*Within IPCC 95% CI* *Outside new calculation 95%CI*

(5) Judgments and conclusions

- The current standard values fall outside the 95% confidence intervals of the new calculated values. However, similarly to the new calculated values, the current calorific values and the 2006 IPCC Guidelines values were calculated from theoretical calorific values and carbon emission factors of propane and butane; most of any difference is probably due to differences in the standard conditions. Therefore, the standard values should be updated to the new calculated values.
- Pure propane and pure butane (n-:i- at 50:50) should be introduced as new entries for reference. The calorific values and carbon emission factors should be calculated annually in order to improve calculation accuracy.

	Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
	GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
Pure propane	**50.35**	**---**	50.35	**16.23**	**---**
Pure butane	**49.43**	---	49.43	**16.72**	---

4-2-2. Gasoline; naphtha

Premium gasoline (reference values); Regular gasoline (reference values); Reformed feedstock oil (reference values)

(1) Calculation method and sample sources

(Gasoline)

Sample sources:	Calorific values and carbon emission factors of premium gasoline and regular gasoline Proportional domestic production levels of premium gasoline and regular gasoline from Mineral Resources and Petroleum Products Statistics
Calculation method:	Class IV, weighted averaging of the calorific values and carbon emission factors of premium gasoline and regular gasoline by domestic production levels of the respective gasolines from Mineral Resources and Petroleum Products Statistics

(FY, 10^3kl)	2008	2009	2010	2011	2012	Mean
Premium gasoline a	8479	8779	8822	8059	7217	8271
Regular gasoline b	48452	48571	49626	46509	46002	47832
(a/(a+b))	0.149	0.153	0.151	0.148	0.136	0.147

(Premium gasoline and regular gasoline)

Sample sources:	Measurements in a survey commissioned by ANRE/METI and GEB/MOE, based on measurement samples obtained with the cooperation of PAJ
Calculation method:	Class III, direct measurement of heat, etc. in the survey commissioned by ANRE/METI and GEB/MOE
Measurement method:	Gross (higher) calorific value measured by the contractor under JIS K2279 (measurements) Composition analysis and physical properties (Density, sulfur content and water content) measured by the contractor under JIS K2249,41,75 (Carbon content and hydrogen content) measured by the contractor under ASTM-D5291
Correction processing:	Gross (higher) calorific value corrected for sulfur content (measured value-0.586*S*D)

(Naphtha and reformed feedstock oil)

Calculation method:	Class IV, estimation from calorific values and carbon emission factors of gasoline. The values of regular gasoline are employed for naphtha and the values of premium gasoline are employed for reformed feedstock oil.

(2) Outline of composition analysis, physical properties and measurements

(Premium gasoline)

	Gross (higher) calorific value GCV MJ/l (corrected)	Density D	Sulfur Swt%	Water Wwt%	Carbon Cwt%	Hydrogen Hwt%
No. of samples used	67	67	67	67	67	67
Maximum	34.54	0.764	0.00	0.03	88.00	14.50
Minimum	32.27	0.732	0.00	0.01	84.70	11.90
Arithmetic mean	33.75	0.748	0.00	0.01	86.90	12.94
Standard deviation	0.465	0.008	0.00	0.01	0.739	0.586

(Regular gasoline)

	Gross (higher) calorific value GCV MJ/l (corrected)	Density D	Sulfur Swt%	Water Wwt%	Carbon Cwt%	Hydrogen Hwt%
No. of samples used	69	69	69	69	69	69
Maximum	34.19	0.746	0.00	0.02	87.10	15.50
Minimum	32.35	0.711	0.00	0.00	83.70	12.80
Arithmetic mean	33.31	0.724	0.00	0.01	85.72	14.10
Standard deviation	0.352	0.008	0.00	0.00	0.680	0.523

(3) Calculation results

(Gasoline)

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
33.37	33.46 / 33.29	45.88	**18.72**	18.78 / 18.67

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
31.33	*31.42 / 31.16*	*43.07*	*19.94*	*19.99 / 19.90*

(Premium gasoline and reformed feedstock oil)

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
33.75	33.84 / 33.65	45.12	**19.26**	19.34 / 19.19

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
31.80	*31.89 / 31.70*	*42.51*	*20.44*	*20.52 / 20.37*

(Regular gasoline and naphtha)

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
33.31	33.39 / 33.23	46.01	**18.63**	18.68 / 18.58

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
31.25	*31.34 / 31.16*	*43.17*	*19.86*	*19.90 / 19.81*

(4) Comparison with current standard values and verification

(Gasoline)

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
34.60	33.37	-0.035	Outside 95%CI	18.29	18.72	+0.024	Outside 95%CI
34.56	33.37	-0.034	Outside 95%CI (Actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
44.32	*43.07*	*-0.030*	*Within IPCC 95% CI* *Outside new calculation 95%CI*	*19.15*	*19.94*	*+0.041*	*Within IPCC 95% CI* *Outside new calculation 95%CI*

(Naphtha)

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
33.60	33.31	-0.009	Outside 95%CI	18.17	18.63	+0.025	Outside 95%CI
33.53	33.31	-0.007	Outside 95%CI (Actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
44.52	*43.17*	*-0.030*	*Within IPCC 95% CI* *Outside new calculation 95%CI*	*19.83*	*19.86*	*+0.004*	*Within IPCC 95% CI* *Within new calculation 95%CI*

(Premium gasoline (reference values; no applicable values in the 2006 IPCC Guidelines))

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
35.10	33.75	-0.039	Outside 95%CI	18.29	19.26	+0.053	Outside 95%CI

(Regular gasoline (reference values; no applicable values in the 2006 IPCC Guidelines))

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
34.50	33.31	-0.035	Outside 95%CI	18.29	18.63	+0.019	Outside 95%CI

(5) Judgments and conclusions

(Gasoline)

- Although the current standard values fall outside the 95% confidence intervals of the new calculated values, the calculation accuracy of the new calculated values is very high and the confidence interval is narrow. The current calorific values are not measured values but were estimated from density measurement examples in FY2000; a lot of time has passed since then. Thus, the supporting premises for the calculations of the current carbon emission factors have been lost. Therefore, the standard values should be updated to new values calculated by weighted averaging by domestic production amounts of the standard values for premium gasoline and regular gasoline, which are based on measurements.
- Currently, the calorific values of gasoline are calculated annually by weighted averaging by domestic production amounts of the standard values of premium gasoline and regular gasoline. To improve the accuracy of calculations, the carbon emission factors should also be calculated annually in the same manner.

(Premium gasoline and regular gasoline (reference values))

- As mentioned above, the current standard calorific values of premium gasoline and regular gasoline are not measured values but were estimated from density measurement examples in FY2000 and a lot of time has passed since then. There are currently no corresponding carbon emission factors. Therefore, the calorific values should be updated to the new calculated values based on measurements and new values for the carbon emission factors should be introduced.

(Naphtha)

- Regular gasoline has similar properties to naphtha. It is valid to use the values for regular gasoline as the calorific values and carbon emission factors of naphtha.
- Although the current standard values fall outside the 95% confidence intervals of the new calculated values, the new calculated values are within a range of about ±2% of the current standard values. The observed cause of this divergence is changes in the standard conditions. The current calorific values were estimated from a small number of calorific values of naphtha for power generation use in Electric Power Statistics, and the supporting premises for the calculations of the current carbon emission factors has been lost. Therefore, the standard values should be updated to the new calculated values.

(Reformed feedstock oil (reference values))

- Reformed feedstock oil is an energy source as important as naphtha in calculating energy and carbon balances for oil refining and petrochemistry. A new entry for reformed feedstock oil should be introduced for reference.
- Premium gasoline has similar properties to reformed feedstock oil. It is valid to use the values for premium gasoline as the calorific values and carbon emission factors of reformed feedstock oil.

4-2-3. Jet fuel

Jet fuel (kerosene type) (reference values); Jet fuel (gasoline type) (reference values)

(1) Calculation method and sample sources

(Jet fuel)

Sample sources:	Calorific values and carbon emission factors of jet fuel (kerosene type) and jet fuel (gasoline type) Proportional consumption amounts of jet fuel by category from General Energy Statistics
Calculation method:	Class IV, weighted averaging of calculated values of calorific values and carbon emission factors of jet fuel (kerosene type) and jet fuel (gasoline type) by consumption amounts by category in General Energy Statistics Estimation with the transport category and manufacturing category being treated as consumption of kerosene type and other categories being treated as consumption of gasoline type

(FY, 10^3kl)	2008	2009	2010	2011	2012	Mean
Transport category, etc. (kerosene type) a	4521	4304	4134	4059	4297	4263
Other categories (gasoline type) b	747	837	923	999	1096	920
(a/(a+b))	0.858	0.837	0.818	0.802	0.797	0.822

(Jet fuel (kerosene type) and jet fuel (gasoline type))

Sample sources:	Measurements in a survey commissioned by ANRE/METI and GEB/MOE, based on measurement samples obtained with the cooperation of PAJ Jet-A-1 standard products were used as samples for kerosene type and JP-4 standard products were used as samples for gasoline type.
Calculation method:	Class III, direct measurement of heat, etc. in the survey commissioned by ANRE/METI and GEB/MOE
Measurement method:	Gross (higher) calorific value measured by the contractor under JIS K2279 (measurements) Composition analysis and physical properties (Density and sulfur content) measured by the contractor under JIS K2249,41 (Carbon and hydrogen contents) measured by the contractor under ASTM-D5291
Correction processing:	Gross (higher) calorific value corrected for sulfur content (measured value-0.586*S*D)

(2) Outline of composition analysis, physical properties and measurements

(Jet fuel (kerosene type))

	Gross (higher) calorific value GCV MJ/l (corrected)	Density D	Sulfur Swt%	Carbon Cwt%	Hydrogen Hwt%
No. of samples used	23	23	23	23	23
Maximum	36.88	0.810	0.17	86.40	14.80
Minimum	36.15	0.786	0.00	85.20	13.50
Arithmetic mean	36.54	0.794	0.02	85.88	14.06
Standard deviation	0.164	0.005	0.04	0.331	0.356

(Jet fuel (gasoline type))

	Gross (higher) calorific value GCV MJ/l (corrected)	Density D	Sulfur Swt%	Carbon Cwt%	Hydrogen Hwt%
No. of samples used	14	14	14	14	14
Maximum	36.13	0.775	0.01	85.90	14.70
Minimum	35.09	0.753	0.00	84.90	14.00
Arithmetic mean	35.43	0.761	0.00	85.47	14.33
Standard deviation	0.289	0.007	0.00	0.284	0.230

(3) Calculation results

(Jet fuel)

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
36.34	36.43 / 36.25	46.13	**18.60**	18.65 / 18.55

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
34.10	*34.19 / 34.01*	*43.29*	*19.82*	*19.87 / 19.77*

(Jet fuel (kerosene type))

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
36.54	36.61 / 36.47	46.04	**18.66**	18.70 / 18.61

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
34.29	*34.36 / 34.21*	*43.20*	*19.88*	*19.93 / 19.83*

(Jet fuel (gasoline type))

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
35.43	35.60 / 35.27	46.57	**18.35**	18.41 / 18.29

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
33.23	*33.40 / 33.07*	*43.68*	*19.57*	*19.63 / 19.50*

(4) Comparison with current standard values and verification

(Jet fuel)

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
36.70	36.34	-0.010	Outside 95%CI	18.31	18.60	+0.016	Outside 95%CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
44.06	*43.29*	*-0.018*	*Within IPCC 95% CI* *Outside new calculation 95%CI*	*19.65*	*19.82*	*+0.009*	*Within IPCC 95% CI* *Outside new calculation 95%CI*

(Jet fuel (kerosene type) (reference value; the 2006 IPCC Guidelines value)

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
44.06	*43.20*	*-0.019*	*Within IPCC 95% CI* *Outside new calculation 95%CI*	*19.65*	*19.88*	*+0.012*	*Within IPCC 95% CI* *Outside new calculation 95%CI*

(Jet fuel (gasoline type) (reference value; the 2006 IPCC Guidelines value)

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
44.32	*43.68*	*-0.014*	*Within IPCC 95% CI* *Outside new calculation 95%CI*	*19.15*	*19.57*	*+0.022*	*Within IPCC 95% CI* *Outside new calculation 95%CI*

(5) Judgments and conclusions

(Jet fuel)

- Although the current standard values fall outside the 95% confidence intervals of the new calculated values, the accuracy of the new calculated values is high and the confidence intervals are narrow. The gross (higher) calorific value and carbon emission factor are within a range of about ±2% of the current standard values. In particular, the gross (higher) calorific value and carbon emission factor almost match the values in the 2006 IPCC Guidelines.

Taken together, these facts indicate that the new calculated values are strongly valid. The standard values should probably be updated to the new calculated values.

- Currently, the standard values used for jet fuel are fixed. To improve the accuracy of calculations, the calorific values and carbon emission factors should be calculated annually by weighted averaging of jet fuel (kerosene type) and jet fuel (gasoline type).

(Jet fuel (kerosene type) and jet fuel (gasoline type) (reference values))

- New entries for jet fuel (kerosene type) and jet fuel (gasoline type) should be introduced for reference.

4-2-4. Kerosene

(1) Calculation method and sample sources

Sample sources:	Measurements in a survey commissioned by ANRE/METI and GEB/MOE, based on measurement samples obtained with the cooperation of PAJ
Calculation method:	Class III, direct measurement of heat, etc. in the survey commissioned by ANRE/METI and GEB/MOE
Measurement method:	Gross (higher) calorific value measured by the contractor under JIS K2279 (measurements) Composition analysis and physical properties (Density, sulfur content, ash content and water content) measured by the contractor under JIS K2249,41,72,75 (Carbon content and hydrogen contents) measured by the contractor under ASTM-D5291
Correction processing:	Gross (higher) calorific value corrected for sulfur content (measured value-0.586*S*D)

(2) Outline of composition analysis, physical properties and measurements

	GCV MJ/l (corrected)	Density D	Sulfur Swt%	Ash Awt%	Water Wwt%	Carbon Cwt%	Hydrogen Hwt%
No. of samples used	23	23	23	23	23	23	23
Maximum	36.98	0.803	0.01	0.00	0.00	86.50	14.20
Minimum	35.96	0.788	0.00	0.00	0.00	85.70	13.40
Arithmetic mean	36.49	0.794	0.00	0.00	0.00	86.02	13.93
Standard deviation	0.222	0.004	0.00	0.00	0.00	0.177	0.191

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
36.49	36.59 / 36.40	45.98	**18.71**	18.75 / 18.66

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
34.27	*34.36 / 34.17*	*43.18*	*19.92*	*19.97 / 19.88*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
36.70	36.49	-0.006	Outside 95%CI	18.51	18.71	+0.011	Outside 95%CI
36.74	36.49	-0.007	Outside 95%CI (Actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
43.82	*43.18*	*-0.015*	*Within IPCC 95% CI*	*19.69*	*19.92*	*+0.012*	*Within IPCC 95% CI*
		Outside new calculation 95%CI				*Outside new calculation 95%CI*	

(5) Judgments and conclusions

- Although the current standard values fall outside the 95% confidence intervals of the new calculated values, the accuracy of the new calculated values is high and the confidence intervals are narrow. The gross (higher) calorific value and carbon emission factor are within a range of about ±2% of the current standard values. In particular, the gross (higher) calorific value and carbon emission factor almost match the values in the 2006 IPCC Guidelines. Taken together, these facts indicate that the new calculated values are strongly valid. The standard values should probably be updated to the new calculated values.

4-2-5. Gas oil / diesel oil

(1) Calculation method and sample sources

Sample sources:	Measurements in a survey commissioned by ANRE/METI and GEB/MOE, based on measurement samples obtained with the cooperation of PAJ
Calculation method:	Class III, direct measurement of heat, etc. in the survey commissioned by ANRE/METI and GEB/MOE
Measurement method:	Gross (higher) calorific value measured by the contractor under JIS K2279 (measurements) Chemical composition and physical properties: density, sulfur content, ash content and water content measured by the contractor under JIS K2249,41,72,75; carbon content and hydrogen content measured by the contractor under ASTM-D5291
Correction processing:	Gross (higher) calorific value corrected for sulfur content (measured value-0.586*S*D)

(2) Outline of composition analysis, physical properties and measurements

	GCV MJ/l (corrected)	Density D	Sulfur Swt%	Ash Awt%	Water Wwt%	Carbon Cwt%	Hydrogen Hwt%
No. of samples used	69	69	69	69	69	69	69
Maximum	38.77	0.844	0.00	0.00	0.00	86.90	14.10
Minimum	37.05	0.808	0.00	0.00	0.00	85.80	13.00
Arithmetic mean	38.04	0.828	0.00	0.00	0.00	86.34	13.61
Standard deviation	0.332	0.008	0.00	0.00	0.00	0.228	0.220

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
38.04	38.12 / 37.96	45.94	**18.79**	18.82 / 18.77

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
35.77	*35.85 / 35.69*	*43.20*	*19.99*	*20.01 / 19.97*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
37.70	38.04	+0.009	Outside 95%CI	18.73	18.79	+0.003	Outside 95%CI
37.94	38.04	+0.003	Within 95%CI (Actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
42.98	*43.20*	*+0.005*	*Within IPCC 95% CI*	*20.12*	*19.99*	*-0.006*	*Within IPCC 95% CI*
		Outside new calculation 95%CI				*Outside new calculation 95%CI*	

(5) Judgments and conclusions

- Of the current standard values, the actual calorific values are within the 95% confidence intervals of the new calculated values but the standard calorific values and carbon emission factors are outside the intervals. However, the accuracy of the new calculated values is high and the confidence intervals are narrow. The standard calorific values and carbon emission factors are within a range of about ±1% of the current standard values. In particular, the standard calorific values and carbon emission factors almost match the values in the 2006 IPCC Guidelines. Taken together, these facts indicate that the new calculated values are strongly valid. The standard values should probably be updated to the new calculated values.

4-2-6. Fuel oil A

(1) Calculation method and sample sources

Sample sources:	Measurements in a survey commissioned by ANRE/METI and GEB/MOE, based on measurement samples obtained with the cooperation of PAJ
Calculation method:	Class III, direct measurement of heat, etc. in the survey commissioned by ANRE/METI and GEB/MOE
Measurement method:	Gross (higher) calorific value measured by the contractor under JIS K2279 (measurements) Chemical composition and physical properties: density, sulfur content, ash content and water content measured by the contractor under JIS K2249, 41, 72, 75; carbon content and hydrogen content measured by the contractor under ASTM-D5291
Correction processing:	Gross (higher) calorific value corrected for sulfur content (measured value-0.586*S*D)

(2) Outline of composition analysis, physical properties and measurements

	GCV MJ/l (corrected)	Density D	Sulfur Swt%	Ash Awt%	Water Wwt%	Carbon Cwt%	Hydrogen Hwt%
No. of samples used	23	23	23	23	23	23	23
Maximum	39.72	0.887	0.94	0.00	0.01	87.70	13.40
Minimum	38.30	0.845	0.03	0.00	0.00	86.10	11.80
Arithmetic mean	38.90	0.864	0.39	0.00	0.01	86.99	12.46
Standard deviation	0.370	0.012	0.34	0.00	0.01	0.429	0.410

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
38.90	39.06 / 38.74	45.02	**19.32**	19.42 / 19.22

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
36.73	*36.90 / 36.56*	*42.51*	*20.46*	*20.56 / 20.37*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
39.10	38.90	-0.005	Outside 95%CI	18.90	19.32	+0.022	Outside 95%CI
39.76	38.90	-0.021	Outside 95%CI (actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI

(No applicable values in the 2006 IPCC Guidelines)

(5) Judgments and conclusions

- Although the current standard values fall outside the 95% confidence intervals of the new calculated values, the accuracy of the new calculated values is high and the confidence intervals are narrow. The gross (higher) calorific value and carbon emission factor are within a range of about ±2% of the current standard values. Therefore, the new calculated values are strongly valid. The standard values should probably be updated to the new calculated values.

4-2-7. Fuel oil C

(1) Calculation method and sample sources

Sample sources:	Measurements in a survey commissioned by ANRE/METI and GEB/MOE, based on measurement samples obtained with the cooperation of PAJ
Calculation method:	Class III, direct measurement of heat, etc. in the survey commissioned by ANRE/METI and GEB/MOE
Measurement method:	Gross (higher) calorific value measured by the contractor under JIS K2279 (measurements) Composition analysis and physical properties (Density, sulfur content, ash content and water content) measured by the contractor under JIS K2249,41,72,75 (Carbon content and hydrogen content) measured by the contractor under ASTM-D5291
Correction processing:	Gross (higher) calorific value corrected for sulfur content (measured value-0.586*S*D)

(2) Outline of composition analysis, physical properties and measurements

	GCV MJ/l (corrected)	Density D	Sulfur Swt%	Ash Awt%	Water Wwt%	Carbon Cwt%	Hydrogen Hwt%
No. of samples used	23	23	23	23	23	23	23
Maximum	42.39	1.000	2.93	0.03	0.05	88.60	12.50
Minimum	40.23	0.890	0.07	0.00	0.00	85.80	10.00
Arithmetic mean	41.78	0.971	2.10	0.01	0.02	86.84	10.76
Standard deviation	0.442	0.024	0.74	0.01	0.03	0.655	0.607

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
41.78	41.97 / 41.59	43.05	**20.17**	20.33 / 20.02

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
39.67	*39.89 / 39.46*	*40.88*	*21.24*	*21.40 / 21.09*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
41.90	41.78	-0.003	Within 95%CI	19.54	20.17	+0.032	Outside 95%CI
42.92	41.78	-0.027	Outside 95%CI (actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
40.44	*40.88*	*+0.011*	*Within IPCC 95% CI*	*21.10*	*21.24*	*+0.007*	*Within IPCC 95% CI*
		Outside new calculation 95%CI				*Within new calculation 95%CI*	

Note: The IPCC reference value is the "*Residual Fuel Oil" value.*

(5) Judgments and conclusions

- Although the current standard values fall outside the 95% confidence intervals of the new calculated values, the accuracy of the new calculated values is high and the confidence intervals are narrow. The gross (higher) calorific value and carbon emission factor are within a range of about ±3% of the current standard values and almost match the values in the 2006 IPCC Guidelines. Taken together, these facts indicate that the new calculated values are strongly valid. The standard values should probably be updated to the new calculated values.

4-2-8. Interpolation and approximation equations for oil products

(1) Calculation method and sample sources

Sample sources: Chemical compositions, physical properties, calorific values and carbon emission factors of a total of 311 samples, listed below, of the major oil products from 4-2-2 Gasoline to 4-2-7 Fuel oil C, measured in surveys commissioned by ANRE/METI and GEB/MOE

- Premium gasoline	67 samples
- Regular gasoline	69 samples
- Jet fuel (kerosene type)	23 samples
- Jet fuel (gasoline type)	14 samples
- Kerosene	23 samples
- Gas oil / diesel oil	69 samples
- Fuel oil A	23 samples
- Fuel oil C	23 samples

Sample sources: Regression analysis using all of the 311 samples listed above

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results (not applicable)

(4) Comparison with current standard values and verification (not applicable)

(5) Judgments and conclusions (not applicable)

(6) Results of regression analysis for interpolation and approximation expressions (values in parentheses are p-values)

- Similarly to crude oil, the results of the regression analysis for interpolation and approximation equations revealed accurate estimation equations for the gross (higher) and net (lower) calorific values and carbon emission factors of oil products.
- For estimating gross (higher) calorific values, the equations in JIS K2279 provided excellent approximations for the range from gas/diesel oil to fuel oil C. However, it was found that for lighter components with densities below 0.8 such as kerosene and jet fuel, errors in the equations from JIS K2279 due to the effects of the change to SATP tended to be excessive. It is clear that these equations cannot be used for estimation (see Figs. 4-2-8-11 and 4-2-8-12).

GCV-V = -26.746*D^2 + 85.6799*D + -0.7351*S + 34.4426*A + -22.8068*W
(0.005) (0.000) (0.000) (0.000) (0.000)
- 14.8180 n= 311, R^2= 0.9821, AIC= 242.6674, with the correction of heteroskedasticity
(0.000) (Equation 4-2-8-1

JIS K2279 estimation equation (for reference): GCV-V=[((51.916-8.792*D^2)*(1-0.01*(A+W+S))+0.09420S]*D
Only fuel oil C: GCV-V=[(52.190-8.802*D^2)*(1-0.01*(A+W+S))+0.09420S)*D
n= 311, R^2= 0.3067 (all samples) n=175, R^2 = 0.8983 (excluding gasoline)

GCV-V = -41.1651*D^2 + 95.5589*D + -1.8167*DMGP + -1.4167*DMGR
(0.000) (0.000) (0.000) (0.000)
+ -0.4973*DMJK + -0.5659*DMJG + -0.5390*DMKE + 0.7054*DMFC - 12.8765
(0.000) (0.000) (0.000) (0.000) (0.000)
n= 311, R^2= 0.9936, AIC= -69.44979, with the correction of heteroskedasticity (Equation4-2-8-2

D = -0.0871*GCV-V + 0.0015*GCV-V^2 +0.0117*S + -0.3490*A + 0.2212*W
(0.000) (0.000) (0.000) (0.110)x (0.000)
+ -0.0177*DMGR + -0.0102*DMJG + 0.0074*DMFA + 1.9941
(0.000) (0.000) (0.000) (0.000)
n= 311, R^2= 0.9946, AIC= -2396.305, with the correction of heteroskedasticity (Equation4-2-8-3

D = -0.0130*GCV-W + 0.0137*S + 0.2345*W + -0.0930*DMGP + -0.1045*DMGR
(0.000) (0.000) (0.000) (0.000) (0.000)
+-0.0325*DMJK + -0.0581*DMJG + -0.0335*DMKE + 0.0186*DMFA +0.0720*DMFC
(0.000) (0.000) (0.000) (0.000) (0.000)
+1.4264

(0.000)
n= 311, R^2= 0.9883, AIC= -1208.422, with the correction of heteroskedasticity (Equation4-2-8-4

GCV-W = 145.2384*D^2 + -0.7664*S + 33.5608*A + -23.2827*W + 46.8254
(0.002) (0.148)x (0.002) (0.017) (0.000)
n= 311, R^2= 0.7370, Adj-R^2= 0.7335 AIC= 406.4675 (Equation4-2-8-5

GCV-W = -11.3012*D^2 + -2.2485*DMGP + -1.7593*DMGR + -0.5389*DMJK
(0.000) (0.000) (0.000) (0.000)
+ -0.5828*DMJG + -0.5917*DMKE + -0.2322*DMFA + 53.6945
(0.000) (0.000) (0.000) (0.000)
n= 311, R^2= 0.9058, AIC= 93.07465, with the correction of heteroskedasticity (Equation4-2-8-6

CEF-G = 1.4449*D^2 + 0.4250*S + -27.6919*A + 19.1905*W + 17.8443
(0.000) (0.000) (0.244) (0.006) (0.000)
n= 311, R^2= 0.6191, AIC= 152.6318, with the correction of heteroskedasticity (Equation4-2-8-7

CEF-G = 15.0788*D +-0.1273*S + 1.6675*DMGP + 1.3978*DMGR + 0.3743*DMJK
(0.000) (0.002) (0.000) (0.000) (0.000)
+ 0.5651*DMJG + 0.4231*DMKE + -0.5109*DMFC +6.3162
(0.000) (0.000) (0.000) (0.000)
n= 311, R^2= 0.8795, AIC= -197.1363, with the correction of heteroskedasticity (Equation4-2-8-8

CEF-G = -0.5375*GCV-W + 0.0285*DMGP +-0.1252*DMGR +-0.0863*DMJK
(0.000) (0.374)x (0.000) (0.000)
+ -0.1020*DMJG + -0.0639*DMKE +0.0354*DMFA +-0.1704*DMFC + 43.4857
(0.000) (0.000) (0.217)x (0.039) (0.000)
n= 311, R^2= 0.9480, AIC= -458.7499, with the correction of heteroskedasticity (Equation4-2-8-9

NCV-V = -24.1010*D^2+ 80.0996*D + -0.5697*S + 25.7882*A + -18.0709*W
(0.000) (0.000) (0.004) (0.011) (0.000)
+-112.3685
(0.000) n=311, R^2= 0.9865, AIC= 137.22, with the correction of heteroskedasticity (Equation4-2-8-10

NCV-V = 1.0076*GCV-V + 0.3531*DMGP + 0.2495*DMGR + 0.0330*DMJK
(0.000) (0.000) (0.000) (0.141)x
+ 0.0933*DMJG + 0.0549*DMKE + 0.0954*DMFA + 0.1393*DMFC + -2.5619
(0.000) (0.008) (0.000) (0.007) (0.000)
n= 311, R^2= 0.9995, AIC= -851.7056, with the correction of heteroskedasticity (Equation4-2-8-11

NCV-W = -0.6941*D^2 + -0.8810*S + 28.9458*A + -25.5401*W + 43.6187
(0.015) (0.000) (0.008) (0.001) (0.000)
n= 311, R^2= 0.7094, AIC= 300.5065, with the correction of heteroskedasticity (Equation4-2-8-12

NCV-W = 0.8815*GCV-W + 0.0373*DMGP + -0.0915*DMGR + -0.0802*DMJK
(0.000) (0.035) (0.000) (0.000)
+-0.0712*DMJG + -0.0592*DMKE + 0.1231*DMFA + 0.2319*DMFC + 2.6995
(0.005) (0.002) (0.000) (0.000) (0.010)
n= 311, R^2= 0.9877, Adj-R^2= 0.9874, AIC= -675.8705 (Equation4-2-8-13

CEF-N = 1.9552*D + 0.4006*S + -25.0852*A + 18.5655*W + 18.4066
(0.000) (0.000) (0.001) (0.000) (0.000)
n=311, R^2= 0.5975, AIC= 118.192, with the correction of heteroskedasticity (Equation4-2-8-14

CEF-N = 14.0119*D + -0.1388*S + 1.5724*DMGP + 1.3223*DMGR + 0.3708*DMJK
(0.000) (0.001) (0.000) (0.000) (0.000)
+ 0.5162*DMJG + 0.4117*DMKE + -0.4562*DMFC + 8.3913
(0.000) (0.000) (0.000) (0.000)
n= 311, R^2= 0.8669, AIC= -217.9837, with the correction of heteroskedasticity (Equation4-2-8-15

CEF-N = -0.5218*NCV-W + 0.0994*DMGP + -0.1452*DMGR + -0.1051*DMJK
(0.000) (0.001) (0.000) (0.000)
+-0.1674*DMJG + -0.0753*DMKE + 0.1184*DMFA + 0.0505*DMFC + 42.5265
(0.000) (0.000) (0.000) (0.469)x (0.000)
n= 311, R^2= 0.9229, AIC= -387.9062, with the correction of heteroskedasticity (Equation4-2-8-16

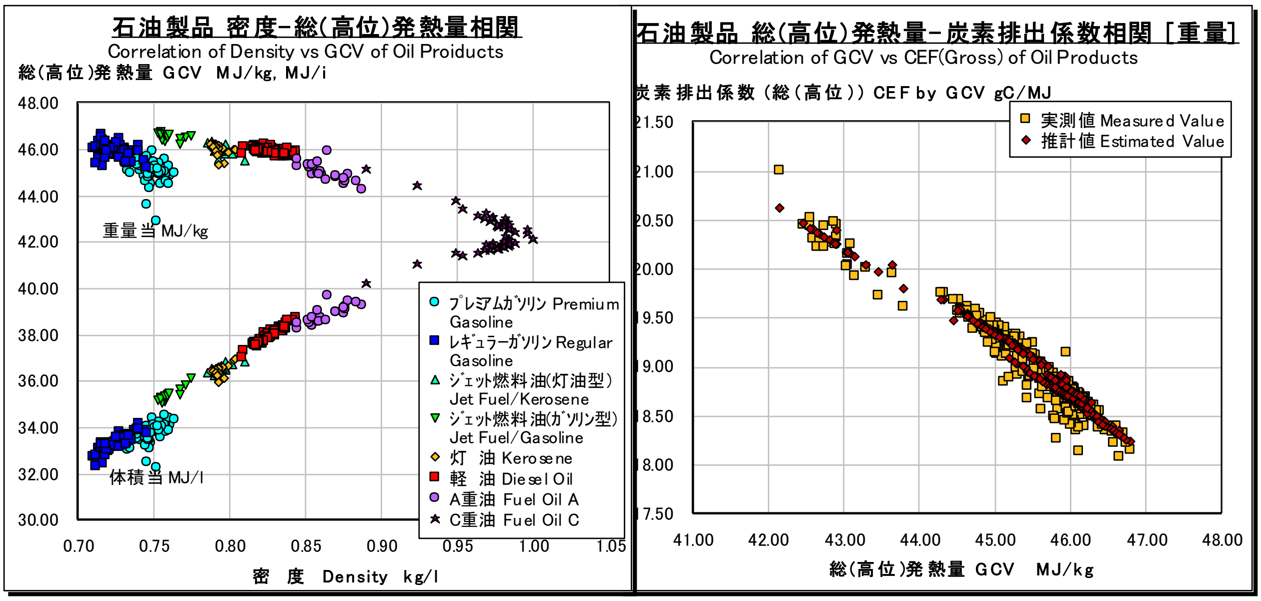
CEF-N = 0.9562*CEF-G + 0.0221*DMGR + 0.0206*DMJK + 0.0152*DMKE
(0.000) (0.000) (0.002) (0.003)
+-0.0331*DMFA + -0.0673*DMFC + 2.0213
(0.000) (0.000) (0.000)
n= 311, R^2= 0.9957, AIC= -1289.122, with the correction of heteroskedasticity (Equation4-2-8-17

GCV	Gross (higher) calorific value -V MJ/l -W MJ/kg	NCV	Net (lower) calorific value -l MJ/l -W MJ/kg
CEF-G	Carbon emission factors (gross (higher)) gC/MJ	CEF-N	Carbon emission factors (net (lower)) gC/MJ
D	Density --	A	Ash content wt%
W	Water content wt%	S	Sulfur content wt%
DMGP	Dummy premium gasoline	DMGR	Dummy regular gasoline
DMJG	Dummy jet fuel (gasoline type)	DMJK	Dummy jet fuel (kerosene type)
DMKE	Dummy kerosene	DMFA	Dummy fuel oil A
DMFC	Dummy fuel oil C		

See the attached figures:

Figs. 4-2-8-1 to 4-2-8-10. Correlations of calorific values vs carbon emission factors for oil products, etc.
Fig. 4-2-8-11. Correlation of estimation errors in standard calorific values based on JIS K2279 vs density
Fig. 4-2-8-12. Correlation of estimation errors in standard calorific values based on new estimation equations vs density

[For reference: Fig. 4-2-8-1. Correlation of density vs gross (higher) calorific value for oil products; Fig. 4-2-8-8. Correlation of gross (higher) calorific value vs carbon emission factor]



4-2-9. Lubricant oil

(1) Calculation method and sample sources

Sample sources:

Estimation from the current standard calorific values

The current standard calorific values still use a legacy value (40.20 MJ/L) from before FY1999, by reference to values including a value estimated by the method described in JIS K2279 from density values measured by PAJ in FY1994.

Calculation method:

Class IV, estimation using the interpolation and approximation equations for oil products

The current standard calorific value of 40.20 MJ/L was substituted into equation 4-2-8-3 to find an estimated density (0.9032). The estimation equations listed below were used for estimation from this estimated density and the standard calorific values given above.

- Gross (higher) calorific value by mass Equation 4-2-8-6,
- Carbon emission factor (gross (higher)) Equation 4-2-8-8,
- Net (lower) calorific value by volume Equation 4-2-8-11, by mass Equation 4-2-8-13,
- Carbon emission factor (net (lower)) Equation 4-2-8-15

Ash, water and sulfur contents are assumed to be the same as the current measured values for fuel oil A.

Where the above equations include the term "DMFA" (dummy fuel oil A), its value is 1.

The 95% confidence intervals of the estimated values are estimated from the 95% confidence intervals of the independent variable factors in the interpolation and approximation equations.

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
40.20	--- / ---	44.24	**19.89**	21.42 / 18.35

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
37.94	*38.92 / 36.97*	*41.70*	*20.99*	*22.50 / 19.48*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
40.20	40.20	---	(Identical)	19.22	19.89	+0.035	Within 95%CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
40.19	*41.70*	*+0.038*	*Within IPCC 95% CI*	*20.00*	*20.99*	*+0.050*	*Within IPCC 95% CI*
		Outside new calculation 95%CI				*Within new calculation 95%CI*	

(5) Judgments and conclusions

- Although the calorific values and carbon emission factors are estimated from the interpolation and approximation equations for oil products and the current standard calorific values, the current carbon emission factors and the calorific values and carbon emission factors in the 2006 IPCC Guidelines are within the 95% confidence intervals. The estimation results apparently have a degree of accuracy. Therefore, the standard values should be updated to the new calculated values.

4-2-10. Miscellaneous heavy oil products; Asphalt (reference values)

(1) Calculation method and sample sources

Sample sources:

Estimation from the current actual calorific values.

The current actual calorific values of miscellaneous heavy oil products and asphalt were calculated from annual production amounts and energy balances of atmospheric residue and fuel oil C, and use the same values.

Calculation method:

Class IV, estimation using the interpolation and approximation equations for oil products. The current actual calorific value of 41.87 MJ/kg was substituted into equation 4-2-8-4 to find an estimated density (0.9861). The estimation equations listed below were used for estimation from this estimated density and the standard calorific values given above.

- Carbon emission factors (gross (higher))	Equation 4-2-8-8,
- Net (lower) calorific value by mass	Equation 4-2-8-13,
- Carbon emission factors (net (lower))	Equation 4-2-8-15

Ash, water and sulfur contents are assumed to be the same as the current measured values of fuel oil C.

Where the above equations include the term "DMFC" (dummy fuel oil C), its value is 1.

The 95% confidence intervals of the estimated values are estimated from the 95% confidence intervals of the independent variable factors in the interpolation and approximation equations.

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
41.87	**--- / ---**	41.87	**20.41**	22.08 / 18.73

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
39.77	*40.79 / 38.75*	*39.77*	*21.46*	*23.11 / 19.81*

(4) Comparison with current standard values and verification (asphalt values from the 2006 IPCC Guidelines)

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
40.90	41.87	+0.024	Outside 95%CI	20.77	20.41	-0.017	Within 95%CI
41.87	41.87	---	(Identical) (actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
40.19	*39.77*	*-0.011*	*Within IPCC 95% CI*	*22.00*	*21.48*	*-0.025*	*Within IPCC 95% CI*
		Within new calculation 95%CI				*Within new calculation 95%CI*	

(5) Judgments and conclusions

- Although the calorific values and carbon emission factors are estimated from the interpolation and approximation equations for oil products and the current actual calorific values, the current carbon emission factors and the calorific values and carbon emission factors in the 2006 IPCC Guidelines are within the 95% confidence intervals. The estimation results apparently have a degree of accuracy. Therefore, the standard values should be updated to the new calculated values.

4-2-11. Fuel oil B (reference values)

(1) Calculation method and sample sources

Sample sources:

Estimation from the current standard calorific values

The current standard calorific values still use a legacy value (40.40 MJ/L) from before FY1999, by reference to values including a value estimated by the method described in JIS K2279 from density values measured by PAJ in FY1992–1996.

Calculation method:

Class IV, estimation using the interpolation and approximation equations for oil products. The current standard calorific value of 40.40 MJ/L was substituted into equation 4-2-8-3 to find an estimated density (0.9097). The estimation equations listed below were used for estimation from this estimated density and the standard calorific values given above.

- Gross (higher) calorific value by mass	Equation 4-2-8-6,
- Carbon emission factor (gross (higher))	Equation 4-2-8-8,
- Net (lower) calorific value by volume	Equation 4-2-8-11, by mass Equation 4-2-8-13,
- Carbon emission factor (net (lower))	Equation 4-2-8-15

Ash, water and sulfur contents are assumed to be the same as the current measured values for fuel oil A.

Where the above equations include the term "DMFA" (dummy fuel oil A), its value is 1.

The 95% confidence intervals of the estimated values are estimated from the 95% confidence intervals of the independent variable factors in the interpolation and approximation equations.

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
40.40	--- / ---	44.11	**19.98**	21.53 / 18.44

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
38.15	*39.13 / 37.16*	*41.58*	*21.08*	*22.61 / 19.56*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
40.40	40.40	---	(Identical)	19.22	19.98	+0.040	Within 95%CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI

(No applicable values in the 2006 IPCC Guidelines)

(5) Judgments and conclusions

- Although the calorific values and carbon emission factors are estimated from the interpolation and approximation equations for oil products and the current standard calorific values, the current carbon emission factors are within the 95% confidence intervals. The estimation results apparently have a degree of accuracy. Therefore, the standard values should be updated to the new calculated values.

4-2-12. Fuel oil C for power generation use (reference values)

(1) Calculation method and sample sources

Sample sources:

Estimation from the current actual calorific values.

Annual calculations of the actual calorific values of fuel oil C for power generation use from averages of the calorific values of fuel oil C in Electric Power Statistics

Calculation method:

Class IV, estimation using the interpolation and approximation equations for oil products. The current standard calorific value of 41.16 MJ/L was substituted into equation 4-2-8-3 to find an estimated density (0.9474). The estimation equations listed below were used for estimation from this estimated density and the standard calorific values given above.

- Gross (higher) calorific value by mass Equation 4-2-8-6,
- Carbon emission factor (gross) Equation 4-2-8-8,
- Net calorific value by volume Equation 4-2-8-11, by mass Equation 4-2-8-13,
- Carbon emission factor (net) Equation 4-2-8-15

Ash, water and sulfur contents are assumed to be the same as the current measured values for fuel oil C.

Where the above equations include the term "DMFC" (dummy fuel oil C), its value is 1.

The 95% confidence intervals of the estimated values are estimated from the 95% confidence intervals of the independent variable factors in the interpolation and approximation equations.

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/l	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
41.16	--- / ---	43.55	**19.82**	21.43 / 18.22

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/l	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
39.05	*40.05 / 38.05*	*41.32*	*20.92*	*22.50 / 19.33*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
41.20	41.16	-0.001	---	19.54	19.82	+0.015	Within 95%CI
41.16	41.16	---	(Identical) (actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
40.44	*41.55*	*+0.022*	*Within IPCC 95% CI*	*21.10*	*20.92*	*-0.009*	*Within IPCC 95% CI*
	Within new calculation 95%CI					*Within new calculation 95%CI*	

(5) Judgments and conclusions

- Although the calorific values and carbon emission factors are estimated from the interpolation and approximation equations for oil products and the current actual calorific values, the current carbon emission factors and the calorific values and carbon emission factors in the 2006 IPCC Guidelines are within the 95% confidence intervals. The estimation results apparently have a degree of accuracy. Therefore, the standard values should be updated to the new calculated values.

4-2-13. Petroleum coke

(1) Calculation method and sample sources

Sample sources:	Measured values provided by a number of member companies of the Japan Chemical Industry Association
Calculation method:	Class II, direct measurement of heat, etc. with the cooperation of the companies mentioned above
Measurement method:	Gross (higher) calorific value (moisture free) measured under JIS-M8814 or ASTM-D5865 Composition analysis (proportional carbon content, etc.) measured under JIS-M8812, 8813 or ASTM-D5373, D3302, D4931
Correction processing:	Corrected by total moisture content to "wet coal (with moisture and ash)" standard

(2) Outline of composition analysis, physical properties and measurements

	GCV MJ/kg (dry)	Carbon contents (dry)	Hydrogen contents (dry)	Total moisture (dry)	Ash (dry)
No. of samples used	85	18	19	80	80
Maximum	36.60	0.912	0.040	0.150	0.009
Minimum	34.64	0.860	0.028	0.003	0.001
Arithmetic mean	35.93	0.887	0.035	0.076	0.003
Standard deviation	0.422	0.015	0.003	0.031	0.002

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
33.29	33.58 / 33.01	33.29	**24.50**	24.69 / 24.31

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
32.79	*33.49 / 32.08*	*32.79*	*25.04*	*25.25 / 24.84*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
29.90	33.29	+0.113	Outside 95%CI	25.35	24.50	-0.034	Outside 95%CI

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
32.48	*32.79*	*+0.009*	*Within IPCC 95% CI*	*26.69*	*25.04*	*-0.062*	*Within IPCC 95% CI*
		Within new calculation 95%CI				*Outside new calculation 95%CI*	

(5) Judgments and conclusions

- The current standard calorific values are measurements from 15 samples provided by the Japan Cement Association in 2005. It is likely that the reason they provided lower values than the new calculated values is because the average water content of those usage samples was 12%.
- Although the current standard values fall outside the 95% confidence intervals of the new calculated values, the accuracy of the new calculated values is very high and the confidence intervals are very narrow. The new calculated values excellently match the calorific values in the 2006 IPCC Guidelines. Both the calorific values and the carbon emission factors should be updated to the new calculated values.

4-2-14. Refinery gas

(1) Calculation method and sample sources

Sample sources:	Measurements provided by PAJ
Calculation method:	Class II, Weighted averaging of pure components with the cooperation of PAJ
Measurement method:	Composition analysis values measured at respective refineries under JIS K2301
Correction processing:	(not applicable)

(2) Outline of composition analysis, physical properties and measurements

(mol %)	Hydrogen	Methane	Ethane	Propane	n-butane	i-butane
No. of samples used	22	22	22	22	22	22
Maximum	59.15	46.41	22.90	23.39	24.43	11.91
Minimum	3.69	6.70	6.39	0.10	0.00	0.00
Arithmetic mean	33.67	20.48	12.81	8.19	6.24	3.40
Standard deviation	14.65	10.07	3.69	5.21	5.08	3.75

(mol %)	Ethylene	Propylene	n-pentane	Carbon monoxide	Carbon dioxide	Nitrogen
No. of samples used	22	22	22	22	22	22
Maximum	19.70	9.70	15.80	2.01	1.30	11.94
Minimum	0.00	0.00	0.00	0.00	0.00	0.00
Arithmetic mean	4.05	3.93	1.90	0.33	0.26	4.60
Standard deviation	4.92	2.80	3.17	0.49	0.32	3.46

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/m^3SATP	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
46.73	52.01 / 41.45	50.81	**14.44**	14.85 / 14.03

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/m^3SATP	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
42.98	*48.07 / 45.29*	*46.68*	*15.71*	*16.13 / 15.29*

(4) Comparison with current standard values and verification (Note: The current standard calorific values are corrected to SATP.)

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
41.14	46.73	+0.136	*Outside 95%CI*	14.15	14.44	+0.021	*Within 95%CI*

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
49.52	*46.68*	*-0.057*	*Outside IPCC 95%CI*	*15.72*	*15.71*	*-0.001*	*Within IPCC 95% CI*
			Within new calculation 95%CI				*Within new calculation 95%CI*

Note: The refinery gas confidence intervals are estimated from the 2006 IPCC Guidelines; care is required.

(5) Judgments and conclusions

- The new calculated calorific value is much higher than the current calorific value corrected to SATP. The average value of 17 samples provided by PAJ for the previous revision was 48.5 MJ/m^3-N (44.4 MJ/m^3 @SATP), which is larger than the current value. However, because it was within the confidence interval, the value was not revised then. It seems that the current increase is valid.
- The carbon emission factors of the new calculated values excellently match the current standard values and the 2006 IPCC Guidelines. The standard values should be updated to the new calculated values.

4-2-15. Sulfur (Recovered sulfur) (reference values)

(1) Calculation method and sample sources

Sample sources:	Theoretical calorific value of sulfur
Calculation method:	Class I, calculation of the theoretical calorific value of sulfur

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results (The net (lower) calorific value is identical with the gross (higher) calorific value.)

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
9.256	---	9.26	**0.00**	---

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
9.29	9.26	-0.004	---	0.00	0.00	+0.000	---

(5) Judgments and conclusions

- The current calorific value is a value under normal conditions (0ºC, 1 atm). The standard value should be updated to the calorific value under SATP conditions (25ºC, 10^5 Pa).

5. Results (3) Natural Gas and Renewable & Recovered Energy

5-1. Natural gas

5-1-1. Imported natural gas: liquefied natural gas (LNG)
Imported natural gas (regasified LNG, reference values)

(1) Calculation method and sample sources

Sample sources:

Chemical compositions by producing region from "Gas Industry Hand Book", published by the Japan Gas Association[*23]

Import shares from Trade Statistics of Japan

Calculation method:

Class I, estimation of theoretical calorific values and carbon emission factors by weighted averaging of chemical compositions of LNG by producing region

Calorific values and carbon emission factors calculated by weighted averaging by import amounts by country (producing region) from Trade Statistics of Japan

Indonesia includes two producing regions, East Kalimantan and North Sumatra, assumed to be 50:50 in proportion.

(FY, 10^3t)	2008	2009	2010	2011	2012	Mean
USA	875	896	663	242	208	577
Brunei	7400	7276	6787	6176	5880	6704
Indonesia	11936	9848	11271	6946	5158	9368
Australia	12424	11567	13590	13410	16740	13546
Malaysia	16671	15243	17216	15126	14425	15736
Qatar	8632	7515	7961	14178	15252	10707
(Subtotal) a	57938	52343	57487	56078	57661	56301
Total imports b	68135	66354	70562	83183	86865	75020
Share a/b	0.850	0.789	0.815	0.674	0.664	0.750

Correction processing: (not applicable)

(2) Outline of composition analysis, physical properties and measurements (taken from Gas Industry Hand Book)

(mol %)	Methane	Ethane	Propane	n-butane	i-butane	n-pentane	Nitrogen
Alaska	99.81	0.070	0.000	0.000	0.000	0.000	0.120
Brunei	90.48	5.110	2.890	0.630	0.810	0.040	0.040
East Kalimantan	89.48	5.210	3.630	0.790	0.870	0.010	0.010
North Sumatra	89.61	8.030	1.550	0.340	0.400	0.030	0.040
Australia	87.40	8.240	3.340	0.400	0.540	0.030	0.050
Malaysia	91.00	5.050	2.860	0.530	0.440	0.010	0.110
Qatar	90.16	6.360	2.230	0.410	0.610	0.020	0.210
(Arithmetic mean)	91.13	5.439	2.357	0.443	0.524	0.020	0.083

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
54.48	54.81 / 54.16	54.48	**13.95**	14.12 / 13.78

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
49.67	*49.91 / 49.44*	*49.67*	*15.30*	*15.47 / 15.14*

[*23] See reference 12. Some corrections were made in January 2016 as it was confirmed that the original values were mol% basis.

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
54.60	54.48	-0.003	Within 95%CI	13.47	13.95	+0.036	Outside 95%CI
54.67	54.48	+0.002	Within 95%CI (actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
47.95	*49.67*	*+0.036*	*Within IPCC 95% CI*	*15.30*	*15.30*	*+0.000*	*Within IPCC 95% CI*
			Within new calculation 95%CI				*Within new calculation 95%CI*

(5) Judgments and conclusions

- The current standard calorific values are within the 95% confidence interval of the new calculated value.
  Although the current standard carbon emission factors fall outside the 95% confidence intervals of the new calculated values, the accuracy of the new calculated values is very high and the confidence intervals are very narrow. The new calculated values excellently match the current standard values and the carbon emission factors in the 2006 IPCC Guidelines. The calorific values and carbon emission factors should be updated to the new calculated values.
- Although it is apparent that variations in the current values and carbon emission factors of LNG from each producing region are very small, relatively large variations in import amounts from the respective producing regions can be seen. Given that the imported amounts are very large, the effect on emissions of these variations in emission factors cannot be ignored. In the future, increases in imports of shale gas[*24], which has a similar composition to natural gas from Alaska, are expected. To improve future calculation accuracy, calorific values and carbon emission factors should be calculated annually by weighted averaging.
- On the basis of these values, a new entry for imported natural gas in gas form (regasified LNG) should be introduced as reference values.

(Reference values: imported natural gas in gas form (regasified LNG, a gas at SATP))

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/m^3@SATP	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
40.47	41.99 / 38.94	54.48	**13.95**	14.12 / 13.78

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/m^3@SATP	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
36.90	*38.33 / 35.46*	*49.67*	*15.30*	*15.47 / 15.14*

[Table 5-1-1-1. Calculation results of gross (higher) calorific values and carbon emission factors for LNG by producing region (reference values)]

	GCV MJ/kg	(Deviation from mean)	CEF-G	(Deviation)
Alaska	55.38	+1.64%	13.49	-3.29%
Brunei	54.51	+0.04%	13.96	-0.07%
East Kalimantan	54.42	-0.12%	14.02	+0.48%
Sumatra	54.63	+0.26%	13.91	-0.33%
Australia	54.38	-0.02%	14.03	+0.53%
Malaysia	54.54	+0.11%	13.91	-0.26%
Qatar	54.45	-0.07%	13.92	-0.22%
(Weighted average)	54.48	---	13.89	---

[*24] The greatest effects on the composition of LNG come from differences in recovery rates of propane and butane depending on the choice of liquefaction refrigerant. LNG produced in the USA, including shale gas, uses ethane as a refrigerant and a high proportion of the propane and butane components is being recovered.

5-1-2. Indigenous natural gas

Gas from water-soluble gas fields (reference values); Associated gas from oilfields and gas from other fields (reference values)

(1) Calculation method and sample sources

Sample sources:	Measurements provided by Japan Natural Gas Association
Calculation method:	Class II, Weighted averaging of pure components with the cooperation of Japan Natural Gas Association
Measurement method:	Composition analysis, measured at producing sites, JIS K2301
Correction processing:	(not applicable)

(2) Outline of composition analysis, physical properties and measurements

(All samples calculated for indigenous natural gas)

(mol %)	Methane	Ethane	Propane	n-butane	i-butane	n-pentane	n-hexane	Carbon dioxide
No. of samples used	289	277	226	226	226	226	226	220
Maximum	99.34	13.60	10.38	3.32	1.59	1.45	1.41	3.75
Minimum	68.80	0.00	0.03	0.00	0.01	0.00	0.00	0.03
Arithmetic mean	88.20	5.67	3.63	0.96	0.66	0.47	0.47	1.22
Standard deviation	7.57	3.61	2.33	0.71	5.08	0.33	4.92	0.85

(Gas from water-soluble gas fields)

(mol %)	Methane	Ethane	Propane	n-butane	i-butane	n-pentane	n-hexane	Carbon dioxide
No. of samples used	69	57	6	6	6	6	6	6
Maximum	99.34	0.17	0.06	0.01	0.01	0.00	0.00	3.75
Minimum	95.64	0.00	0.03	0.00	0.01	0.00	0.00	0.57
Arithmetic mean	98.15	0.03	0.05	0.01	0.01	0.00	0.00	1.64
Standard deviation	1.12	0.04	0.01	0.00	0.00	0.00	0.00	0.96

(Associated gas from oilfields and gas from other fields)

(mol %)	Methane	Ethane	Propane	n-butane	i-butane	n-pentane	n-hexane	Carbon dioxide
No. of samples used	220	220	220	220	220	220	220	220
Maximum	92.86	13.60	10.38	3.32	1.59	1.45	1.41	2.87
Minimum	68.80	3.55	1.26	0.31	0.21	0.09	0.03	0.03
Arithmetic mean	85.07	7.14	3.72	0.99	0.68	0.49	0.26	1.03
Standard deviation	5.83	2.45	2.29	0.70	0.33	0.32	0.26	0.71

Note: There are also impurity gases such as nitrogen.

(3) Calculation results

(All samples calculated for indigenous natural gas)

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/m^{3}SATP	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
40.15	40.56 / 39.74	52.69	**13.97**	14.01 / 13.93

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/m^{3}SATP	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
36.62	*37.00 / 36.23*	*48.04*	*15.32*	*15.36 / 15.28*

(4) Comparison with current standard values and verification (Note: The current standard calorific values are corrected to SATP.)

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
39.85	40.15	+0.007	Within 95%CI	13.90	13.97	+0.005	Outside 95%CI
41.00	40.15	-0.021	Outside 95%CI (actual calorific values from FY2012)				

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
47.95	*48.04*	*+0.002*	*Within IPCC 95% CI* *Within new calculation 95%CI*	*15.30*	*15.32*	*+0.001*	*Within IPCC 95% CI* *Within new calculation 95%CI*

(5) Judgments and conclusions

- Although the current standard values fall outside the 95% confidence intervals of the new calculated values, the accuracy of the new calculated values is very high and the confidence intervals are very narrow. The new calculated values excellently match, within ±1%, the current standard values and the carbon emission factors in the 2006 IPCC Guidelines. The calorific values and carbon emission factors should be updated to the new calculated values.
- The properties of indigenous natural gas differ between gas from water-soluble gas fields, which is almost pure methane at 98% by mass or more, and associated gas from oil fields and gas from other fields, which contain about 85% by mass ethane and propane. It is understood that the calorific values and carbon emission factors are different; so, respective new entries should be introduced for reference.

(Gas from water-soluble gas fields) (reference values)

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/m^{3}SATP	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
35.74	35.84 / 35.64	52.93	**13.49**	13.49 / 13.49

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/m^{3}SATP	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
32.47	*32.57 / 32.38*	*48.09*	*14.85*	*14.85 / 14.85*

(Associated gas from oilfields and gas from other fields) (reference value)

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/m^{3}SATP	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
41.53	41.92 / 41.15	52.61	**14.12**	14.15 / 14.08

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/m^{3}SATP	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
37.92	*38.27 / 37.56*	*48.02*	*15.46*	*15.50 / 15.43*

5-1-3. Coal mining gas (reference values)

(1) Calculation method and sample sources

Sample sources:	Calorific value: Current standard value (legacy values from before the FY2000 revision) Carbon emission factor: Current standard value (carbon emission factors of indigenous natural gas)
Calculation method:	Class V, keeping the calorific values at the current standard values and updating the carbon emission factors to the values of indigenous natural gas from water-soluble gas fields

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results (not applicable)

(4) Comparison with current standard values and verification (not applicable)

(5) Judgments and conclusions

- A gross (higher) calorific value of 15.3 MJ/kg can be used, as in the current standard values. Gas from water-soluble gas fields has similar properties; so, 13.5g C/MJ can be used for the corresponding carbon emission factor.

5-2. Renewable&recovered energy

5-2-1. Black liquor (reference values)

(1) Calculation method and sample sources

Sample sources:	Measurements provided by the Japan Paper Association
Calculation method:	Class II, direct measurement of heat, etc. with the cooperation of Japan Paper Association
Measurement method:	Measuring gross (higher) calorific value (bone dry), JIS M8814 Composition analysis measurements (carbon content, etc.), JIS M8812 and M8813
Correction processing:	Using the bone dry standard[*25] as the measurement standard for calorific value as in the past, weighted averaging by consumption amounts of the respective samples to set a standard value Estimation of the net (lower) calorific value (bone dry) assuming a hydrogen content of 10.00%, equilibrium moisture of 37.50% and ash content of 20.00%

(2) Outline of composition analysis, physical properties and measurements

	Gross (higher) calorific value GCV MJ/kg (bone dry)	Carbon content (moisture free) wt%
No. of samples used	24	10
Maximum	14.62	36.99
Minimum	12.59	27.33
Arithmetic mean	13.77	32.38
Standard deviation	0.627	3.357

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg (bone dry)	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
13.61	13.87 / 13.34	13.61	**0.00**	---

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg (bone dry)	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
11.90	*12.67 / 11.13*	*11.90*	*0.00*	---

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
13.20	13.61	+0.031	Outside 95%CI	0.00	0.00	---	---

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
11.77	*11.90*	*+0.011*	*(no IPCC intervals)*	*30.68*	*0.00*	---	---

Within new calculation 95%CI (reference value 28.53, -0.070)

(5) Judgments and conclusions

- Although the current standard values fall outside the 95% confidence intervals of the new calculated values, the accuracy of the new calculated values is very high and the confidence intervals are very narrow. The new calculated values excellently match the calorific values in the 2006 IPCC Guidelines. The calorific values should be updated to the new calculated values.
- According to the general rules of renewable energy, the carbon emission factors are zero.

[*25] "Dry conditions" refers to an "absolutely dry" state, meaning a state that has been thoroughly dried until no more water evaporates at a temperature of 105±5ºC. This differs from the "moisture free" state in that some equilibrium water such as crystallization water remains. See Addendum 3.

5-2-2. Waste woods (reference values)

(1) Calculation method and sample sources

Sample sources:	Measurements provided by the Japan Paper Association
Calculation method:	Class II, direct measurement of heat or the like, with the cooperation of the Japan Paper Association
Measurement method	Measuring gross (higher) calorific value (bone dry), JIS M8814 Composition analysis measurements (carbon content, etc.), JIS M8812 and M8813
Correction processing:	Using the bone dry standard as the measurement standard for calorific value as in the past, weighted averaging by consumption amounts of the respective samples to set a standard value Estimation of the net (lower) calorific value (bone dry) assuming a hydrogen content of 7.25%, equilibrium moisture of 10.00% and ash content of 35.00%

(2) Outline of composition analysis, physical properties and measurements

	Gross (higher) calorific value GCV MJ/kg (bone dry)	Carbon content (moisture free) wt%
No. of samples used	23	5
Maximum	22.14	48.96
Minimum	8.83	46.68
Arithmetic mean	17.24	47.75
Standard deviation	2.748	1.048

(3) Calculation results

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/kg (bone dry)	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
17.06	18.25 / 15.87	17.06	**0.00**	---

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/kg (bone dry)	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
15.34	*19.58 / 11.10*	*15.34*	*0.00*	---

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit)				Carbon emission factor CEF-G gC/MJ			
Current value	New calculation	Change	95% CI	Current value	New calculation	Change	95% CI
16.30	17.06	+0.047	Within 95%CI	0.00	0.00	---	---

Net (lower) calorific value NCV MJ/kg				Carbon emission factor CEF-N gC/MJ			
IPCC	New calculation	Change	95% CI	IPCC	New calculation	Change	95% CI
15.60	*15.34*	*-0.017*	*(no IPCC intervals)*	*30.68*	*0.00*	---	---

Within new calculated value interval (reference values 32.88, +0.072)

(5) Judgments and conclusions

- The current standard values are within the 95% confidence intervals of the new calculated values and the new calculated values broadly match the calorific values in the 2006 IPCC Guidelines. The calorific values should be updated to the new calculated values.
- According to the general rules of renewable energy, the carbon emission factors are zero.

5-2-3. Waste tire; Waste plastics; Refuse derived fuel (RDF); Refuse paper and plastic fuel (RPF) (reference values)

(1) Calculation method and sample sources

Sample sources: Calorific values: current standard values (legacy values from FY2005)
Carbon emission factors: 0
Calculation method: Class V, keeping the calorific values at the current standard values
According to the general rules of recovered energy, the carbon emission factors are zero.

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results (not applicable)

(4) Comparison with current standard values and verification (not applicable)

(5) Judgments and conclusions

- The gross (higher) calorific values can be set to the following values as in the current standard values.

Waste tire	33.20 MJ/kg	(with moisture and ash)
Waste plastics	29.30 MJ/kg	(with moisture and ash)
RDF	18.00 MJ/kg	(with moisture and ash)
RPF	26.69 MJ/kg	(with moisture and ash)

- According to the general rules of recovered energy, the energy-derived carbon emission factors are zero for all the energy sources listed here.

5-2-4. Refuse derived gas (reference values)

(1) Calculation method and sample sources

Sample sources: Calorific value: current standard value (a legacy value from FY2005 is converted.)
Carbon emission factor: 0
Calculation method: Class V, The current standard calorific value is converted to standard ambient temperature and pressure.
According to the general rules of recovered energy, the carbon emission factors are zero.

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results (not applicable)

(4) Comparison with current standard values and verification (not applicable)

(5) Judgments and conclusions

- The current standard value (23.40 MJ/m^3-N) is converted to SATP, for a value of 21.44 MJ/m^3 @SATP.
- According to the general rules of recovered energy, the carbon emission factors are zero.

5-2-5. Solid biomass; Liquid biomass (reference values)

(1) Calculation method and sample sources

Sample sources: Calorific values
- Solid: Actual calorific values (Average of measurement values in the Electric Power Statistics)
- Liquid: Gross (higher) calorific value of ethanol

Carbon emission factors: 0
Calculation method: Class V, continuing to use the current actual calorific values for the calorific values
According to the general rules of renewable energy, the carbon emission factors are zero.

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results (not applicable)

(4) Comparison with current standard values and verification (not applicable)

(5) Judgments and conclusions

- For solid biomass, the gross (higher) calorific value can be set to 17.79 MJ/kg (with moisture and ash) as in the current actual calorific values.
- For liquid biomass, the theoretical gross (higher) calorific value of ethanol, 23.42 MJ/L, is set as before. Quantities of liquid biomass fuels with different purities and compositions can be converted for calculations on the basis of this value.
- According to the general rules of renewable energy, the carbon emission factors are zero.

6. Conclusions and Recommendations

6-1. Standard calorific values and carbon emission factors calculated indirectly from these results

6-1-1. Town gas

12A and 13A (reference values); Direct supply of LPG (reference values)

(1) Calculation method and sample sources

Sample sources:	Calorific values and carbon emission factors of LPG, indigenous natural gas and imported natural gas (LNG)[*26]. Annual raw material consumption amounts for supplying town gas (general gas) from METI "Current Survey of Production Concerning Gas Industry"
Calculation method:	Class IV, calculation by weighted averaging of calorific values and carbon emission factors of LPG, indigenous natural gas and imported natural gas (LNG) in accordance with annual consumption amounts of these gases for supplying town gas (general gas) from the Gas Industry Yearbook

(FY / PJ)	2008	2009	2010	2011	2012	Mean	Converted mean*
LPG	42	43	48	53	54	48.2	51.1
Indigenous natural gas	131	127	115	128	121	124.5	121.9
Imported natural gas (LNG)	1439	1424	1553	1591	1590	1519.3	1514.3

*: Energy amounts based on current standard calorific values are converted to be based on calorific values according to the new calculated values.

Correction processing:	Necessary energy consumption and losses in the distribution of town gas are treated as inhouse consumption by town gas companies. The consumption and losses are very small; so, no distinction is made between the gas-sending end and the gas-receiving end.

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results

Gross (higher) calorific value GCV GCV MJ/m^{3}SATP	95% CI	(by mass) GCV MJ/kg	Carbon emission factor CEF-G CEF-G gC/MJ	95% CI
42.18	43.59 / 40.77	54.22	**14.03**	14.17 / 13.89

Net (lower) calorific value (reference value) NCV NCV MJ/m^{3}SATP	95% CI	(by mass) NCV MJ/kg	Carbon emission factor (reference value) CEF-N CEF-N gC/MJ	95% CI
38.50	*39.83 / 37.18*	*49.46*	*15.37*	*15.53 / 15.22*

(4) Comparison with current standard values and verification

Gross (higher) calorific value GCV (original unit) Current value	New calculation	Change	95% CI	Carbon emission factor CEF-G gC/MJ Current value	New calculation	Change	95% CI
41.04	42.18	+0.028	Within 95%CI	13.65	14.03	+0.027	Outside 95%CI

Net (lower) calorific value NCV MJ/kg IPCC	New calculation	Change	95% CI	Carbon emission factor CEF-N gC/MJ IPCC	New calculation	Change	95% CI
47.95	*49.46*	*+0.031*	*Within IPCC 95% CI*	*15.30*	*15.37*	*+0.005*	*Within IPCC 95% CI*
		Within new calculation 95%CI				*Within new calculation 95%CI*	

(5) Judgments and conclusions

- The calorific values and carbon emission factors of town gas are calculated by weighted averaging in accordance with raw material consumption amounts, as in the past. The standard values should be updated to the calculated values in accordance with this calculation approach.
- Of the reference values in the current table of standard calorific values, 4A–7C are types of

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[*26] The values of town gas were also corrected following the confirmation of the basis of composition for LNG.

which there is currently very little supply in Japan due to changes in heat content by the gas companies. Therefore, these values should be removed.

- Of the reference values in the current table of standard calorific values, 12A and 13A are the same as the values for town gas in this entry. "Direct supply of LPG" accounts for values of LPG in the current revision, converted to gasified values.

(Direct supply of LPG) (reference values)

Gross (higher) calorific value GCV		(by mass)	Carbon emission factor CEF-G	
GCV MJ/m^{3}SATP	95% CI	GCV MJ/kg	CEF-G gC/MJ	95% CI
97.73	98.20 / 97.25	50.06	**16.38**	16.39 / 16.37

Net (lower) calorific value (reference value) NCV		(by mass)	Carbon emission factor (reference value) CEF-N	
NCV MJ/m^{3}SATP	95% CI	NCV MJ/kg	CEF-N gC/MJ	95% CI
90.64	*91.09 / 90.19*	*46.43*	*17.66*	*17.67 / 17.66*

6-1-2. Electricity

Supply end calorific value; receiving end calorific value

(1) Calculation method and sample sources

Sample sources:	Generation losses and transmission and distribution efficiencies from Electric Power Statistics and General Energy Statistics
Calculation method:	Class I and IV

Calorific value during consumption: by definition[27], 3.60 MJ/kWh

Generation end calorific value: calculated from a steam power generation efficiency that is calculated from General Electric Utility steam power generation efficiencies in Electric Power Statistics and General Energy Statistics

Receiving end calorific value: calculated from a power generation efficiency and a transmission and distribution efficiency that are calculated from General Electric Utility power generation efficiencies and transmission and distribution efficiencies in Electric Power Statistics and General Energy Statistics

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results (The net (lower) calorific values are identical with the gross (higher) calorific values.)

(Calorific value during consumption)	**3.60** MJ/kWh (by definition)
(Receiving end calorific value)	**9.48** MJ/kWh, 95%CI: 9.50 / 9.47 MJ/kWh
(Generation end calorific value)	**8.68** MJ/kWh, 95%CI: 8.74 / 8.63 MJ/kWh

(4) Comparison with current standard values

(Receiving end calorific value)	Current: 9.63 MJ/kWh, Change: -0.014, Outside the CI
(Generation end calorific value)	Current: 8.81 MJ/kWh, Change: -0.015, Outside the CI

(5) Judgments and conclusions

- The calorific value during consumption, generation end calorific value and receiving end calorific value should be transferred to the main table of standard calorific values and should be recalculated annually.
- The carbon emission factor (the basic unit of carbon dioxide emissions) for consumption of electric power is calculated and published annually for each separate company in compliance with the ordinances of METI and MOE, in accordance with the Act on Promotion of Global Warming Countermeasures. Even if ministerial ordinances do not apply, the carbon emission factors should be separately calculated from the energy sources required for supplies of electric power. Therefore, carbon emission factors are not specified as standard values.

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[27] See Addendum 5 for definitions and detailed calculation procedures for calorific values of electric power.

6-1-3. Heat (Steam)

(1) Calculation method and sample sources

Sample sources:	Latent heat and specific heat of water from "Chronological Scientific Tables", published by National Astronomical Observatory of Japan
Calculation method:	Class I, Calorific value to produce 1 kg of saturated steam at 100°C calculated for SATP conditions (25ºC, 10^5 Pa)

(2) Outline of composition analysis, physical properties and measurements (not applicable)

(3) Calculation results (gross (higher) calorific value)

100°C saturated steam **2.57** MJ/kg (standard ambient temperature and pressure conditions)

(4) Comparison with current standard values

Current: 2.68 MJ/kg (normal standard conditions: 0ºC, 1 atm), Change: -0.040

(5) Judgments and conclusions

- Heat (steam) is based on 100°C saturated steam as in the past but values should be converted from the current normal standard conditions to SATP conditions and updated.
- Carbon emission factors for the consumption of heat (steam) should be separately calculated from the energy sources required for supplies of heat (steam), in the same manner as for electric power. The carbon emission factors are not set as standard values.

6-2. Compilation of results (FY2013 revision: Table of standard calorific values and carbon emission factors (proposed))

6-2-1. Main table

Energy source	Standard gross (higher) calorific value and original unit		Carbon emission factor (gC/MJ)	Remarks
[Coal and Coal products]				
Imported steel making coal	28.79	MJ/kg	24.53	Wet coal, weighted average
Coking coal	28.94	MJ/kg	24.42	Wet coal
PCI coal	28.01	MJ/kg	25.06	Wet coal
Imported steam coal	25.97	MJ/kg	24.42	Wet coal
Imported anthracite	27.80	MJ/kg	25.92	Wet coal
Coke	29.18	MJ/kg	30.22	With moisture and ash
Coke oven gas	19.12	MJ/m^3@SATP	10.93	25°C, 10^{5}Pa
Blast furnace gas	3.284	MJ/m^3@SATP	(Separate calculation)	25°C, 10^{5}Pa
Converter furnace gas	7.640	MJ/m^3@SATP	41.72	25°C, 10^{5}Pa
[Oil]				
Crude oil for refinery use	38.28	MJ/l	19.00	25°C, 10^{5}Pa
NGL/condensate	34.93	MJ/l	18.26	25°C, 10^{5}Pa
LPG	50.06	MJ/kg	16.38	Liquid, weighted average
Naphtha	33.31	MJ/l	18.63	25°C, 10^{5}Pa
Gasoline	33.37	MJ/l	18.72	Weighted average
Jet fuel	36.34	MJ/l	18.60	Weighted average
Kerosene	36.49	MJ/l	18.71	25°C, 10^{5}Pa
Gas/diesel oil	38.04	MJ/l	18.79	25°C, 10^{5}Pa
Fuel oil A	38.90	MJ/l	19.32	25°C, 10^{5}Pa
Fuel oil C	41.78	MJ/l	20.17	25°C, 10^{5}Pa
Lubricant oil	40.20	MJ/l	19.89	25°C, 10^{5}Pa
Miscellaneous heavy oil products	41.87	MJ/kg	20.41	With moisture and ash
Petroleum coke	33.29	MJ/kg	24.50	With moisture and ash
Refinery gas	46.73	MJ/m^3@SATP	14.44	25°C, 10^{5}Pa
[Natural gas and Town gas]				
Imported natural gas (LNG)	54.48	MJ/kg	13.95	Liquid
Indigenous natural gas	40.15	MJ/m^3@SATP	13.97	25°C, 10^{5}Pa
Town gas	42.18	MJ/m^3@SATP	14.03	Weighted average
[Electricity and Heat]				
Calorific value during consumption of electricity	3.600	MJ/kWh	(Separate calculation)	Defined value
Receiving end calorific value of electricity	9.484	MJ/kWh	(Separate calculation)	Calculated value
Generation end calorific value of electricity	8.683	MJ/kWh	(Separate calculation)	Calculated value
Calorific value during consumption of steam	2.571	MJ/kg@SATP	(Separate calculation)	100ºC saturated steam

Attached graphs 6-2-1-1 to 6-2-1-8. Correlations of gross (higher) calorific values vs carbon emission factors (all, solids, liquids, gases)

6-2-2. Reference value table

Energy source	Standard gross (higher) calorific value and original unit		Carbon emission factors (gC/MJ)	Remarks
(Coal, oil and natural gas)				
Indigenous produced steam coal	25.28	MJ/kg	23.74	Wet coal
Lignite or brown coal	13.05	MJ/kg	26.82	Wet coal
Imported steam coal for power generation use	25.97	MJ/kg	24.42	Wet coal
Coal briquette	23.90	MJ/kg	25.92	With moisture and ash
COM	36.20	MJ/kg	21.88	With moisture and ash
CWM	20.90	MJ/kg	24.42	With moisture and ash
Coal tar	37.26	MJ/kg	20.90	With moisture and ash
Blast furnace gas for power generation use	3.403	MJ/m^3@SATP	(Separate calculation)	25°C, 10^{5}Pa
Crude oil for power generation use	39.30	MJ/l	19.14	25°C, 10^{5}Pa
Bituminous mixture fuel	22.44	MJ/kg	19.96	With moisture and ash
Pure propane	50.35	MJ/kg	16.23	Liquid
Pure butane	49.43	MJ/kg	16.72	Liquid
premium gasoline	33.75	MJ/l	19.26	25°C, 10^{5}Pa
Regular gasoline	33.31	MJ/l	18.63	25°C, 10^{5}Pa
Reformed feedstock oil	33.75	MJ/l	19.26	25°C, 10^{5}Pa
Jet fuel (gasoline type)	35.43	MJ/l	18.35	25°C, 10^{5}Pa
Jet fuel (kerosene type)	36.54	MJ/l	18.66	25°C, 10^{5}Pa
Fuel oil B	40.40	MJ/l	19.98	25°C, 10^{5}Pa
Fuel oil C for power generation use	41.16	MJ/l	19.82	25°C, 10^{5}Pa
Asphalt	41.87	MJ/kg	20.41	With moisture and ash
Galvanic furnace gas	7.640	MJ/m^3@SATP	41.72	25°C, 10^{5}Pa
Sulfur	9.255	MJ/kg (dry)	0.00	Theoretical value of pure sulfur
Imported natural gas (regasified LNG)	40.47	MJ/m^3@SATP	13.95	25°C, 10^{5}Pa
Gas from water-soluble gas fields	35.74	MJ/m^3@SATP	13.49	25°C, 10^{5}Pa
Associated gas from oilfields and gas from other fields	41.53	MJ/m^3@SATP	14.12	25°C, 10^{5}Pa
Coal mining gas	15.30	MJ/m^3@SATP	13.49	25°C, 10^{5}Pa
Town gas (12A and 13A)	42.18	MJ/m^3@SATP	14.03	25°C, 10^{5}Pa
Town gas (Direct supply of LPG)	97.73	MJ/m^3@SATP	16.38	25°C, 10^{5}Pa
(Renewable&recovered energy)				
Black liquor	13.61	MJ/kg (bd)	(0.00)	Bone dry with ash
Waste woods	17.06	MJ/kg (bd)	(0.00)	Bone dry with ash
Solid biomass	17.79	MJ/kg (bd)	(0.00)	Bone dry with ash
Liquid biomass	23.42	MJ/l (dry)	(0.00)	Pure ethanol value
Refuse derived gas	21.44	MJ/m^3@SATP	(0.00)	25°C, 10^{5}Pa
Waste tire	33.20	MJ/kg	(0.00)	With moisture and ash
Waste plastics	29.30	MJ/kg	(0.00)	With moisture and ash
RPF	26.69	MJ/kg	(0.00)	With moisture and ash
RDF	18.00	MJ/kg	(0.00)	With moisture and ash

6-2-3. Net (lower) calorific value table (for comparison and reference, by mass net (lower) calorific value)

Energy source	Net (lower) calorific value and original unit		Carbon emission factors (gC/MJ)	Remarks
[Coal and Coal products]				
Imported steel making coal	*26.52*	*MJ/kg NCV*	*26.63*	Wet coal, weighted average
Coking coal	*26.68*	*MJ/kg NCV*	*26.50*	Wet coal
PCI coal	*25.74*	*MJ/kg NCV*	*27.27*	Wet coal
Imported steam coal	*24.66*	*MJ/kg NCV*	*25.68*	Wet coal
Imported anthracite	*26.89*	*MJ/kg NCV*	*26.80*	Wet coal
Coke	*28.81*	*MJ/kg NCV*	*30.60*	With moisture and ash
Coke oven gas	*35.30*	*MJ/kg NCV*	*13.74*	25°C, 10^5Pa
Blast furnace gas	*2.517*	*MJ/kg NCV*	*(Separate calculation)*	25°C, 10^5Pa
Converter furnace gas	*6.149*	*MJ/kg NCV*	*41.92*	25°C, 10^5Pa
[Oil]				
Crude oil for refinery use	*42.30*	*MJ/kg NCV*	*20.18*	25°C, 10^5Pa
NGL/condensate	*43.69*	*MJ/kg NCV*	*19.49*	25°C, 10^5Pa
LPG	*46.43*	*MJ/kg NCV*	*17.66*	Liquid, weighted average
Naphtha	*43.17*	*MJ/kg NCV*	*19.86*	25°C, 10^5Pa
Gasoline	*43.07*	*MJ/kg NCV*	*19.94*	Weighted average
Jet fuel	*43.29*	*MJ/kg NCV*	*19.82*	Weighted average
Kerosene	*43.18*	*MJ/kg NCV*	*19.92*	25°C, 10^5Pa
Gas/diesel oil	*43.20*	*MJ/kg NCV*	*19.99*	25°C, 10^5Pa
Fuel oil A	*42.51*	*MJ/kg NCV*	*20.46*	25°C, 10^5Pa
Fuel oil C	*40.88*	*MJ/kg NCV*	*21.24*	25°C, 10^5Pa
Lubricant oil	*41.70*	*MJ/kg NCV*	*20.99*	25°C, 10^5Pa
Miscellaneous heavy oil products	*39.77*	*MJ/kg NCV*	*21.46*	With moisture and ash
Petroleum coke	*32.79*	*MJ/kg NCV*	*25.04*	With moisture and ash
Refinery gas	*46.68*	*MJ/kg NCV*	*15.71*	25°C, 10^5Pa
[Natural gas and Town gas]				
Imported natural gas (LNG)	*49.67*	*MJ/kg NCV*	*15.30*	Liquid
Indigenous natural gas	*48.04*	*MJ/kg NCV*	*15.32*	25°C, 10^5Pa
Town gas	*49.46*	*MJ/kg NCV*	*15.37*	Weighted average

Note: The net (lower) calorific values and corresponding carbon emission factors in Tables 6-2-3 and 6-2-4 are created for comparison and reference. They are not to be used in calculations of energy supply and demand amounts, energy-derived carbon dioxide emissions and so forth.

The standard values to be used for calculations are the gross (higher) calorific values and corresponding carbon emission factors in Tables 6-2-1 and 6-2-2.

6-2-4. Table of reference values of net (lower) calorific values (for comparison and reference; all net (lower) calorific values by mass)

Energy source	Net (lower) calorific value and original unit		Carbon emission factors(gC/MJ)	Remarks
(Coal, oil and natural gas)				
Indigenous produced steam coal	*23.90*	*MJ/kg NCV*	*25.12*	Wet coal
Lignite or brown coal	*10.98*	*MJ/kg NCV*	*30.02*	Wet coal
Imported steam coal for power generation use	*24.66*	*MJ/kg NCV*	*25.68*	Wet coal
Coal briquette	*23.11*	*MJ/kg NCV*	*26.80*	With moisture and ash
Coal tar (IPCC value)	*28.00*	*MJ/kg NCV*	*22.00*	With moisture and ash
Blast furnace gas for power generation use	*2.608*	*MJ/kg NCV*	*(Separate calculation)*	25°C, 10^5Pa
Crude oil for power generation use	*42.09*	*MJ/kg NCV*	*20.27*	25°C, 10^5Pa
Bituminous mixture fuel (IPCC value)	*27.50*	*MJ/kg NCV*	*21.01*	With moisture and ash
Pure propane	*46.66*	*MJ/kg NCV*	*17.51*	Liquid
Pure butane	*45.94*	*MJ/kg NCV*	*17.99*	Liquid
Premium gasoline	*42.51*	*MJ/kg NCV*	*20.44*	25°C, 10^5Pa
Regular gasoline	*43.17*	*MJ/kg NCV*	*19.86*	25°C, 10^5Pa
Reformed feedstock oil	*42.51*	*MJ/kg NCV*	*20.44*	25°C, 10^5Pa
Jet fuel (gasoline type)	*43.68*	*MJ/kg NCV*	*19.57*	25°C, 10^5Pa
Jet fuel (kerosene type)	*43.20*	*MJ/kg NCV*	*19.88*	25°C, 10^5Pa
Fuel oil B	*41.58*	*MJ/kg NCV*	*21.08*	25°C, 10^5Pa
Fuel oil C for power generation use	*41.32*	*MJ/kg NCV*	*20.92*	25°C, 10^5Pa
Asphalt	*39.77*	*MJ/kg NCV*	*21.46*	With moisture and ash
Galvanic furnace gas	*6.149*	*MJ/kg NCV*	*41.92*	25°C, 10^5Pa
Imported natural gas (regasified LNG)	*49.67*	*MJ/kg NCV*	*15.30*	25°C, 10^5Pa
Gas from water-soluble gas fields	*48.09*	*MJ/kg NCV*	*14.85*	25°C, 10^5Pa
Associated gas from oilfields and gas from other fields	*48.02*	*MJ/kg NCV*	*15.46*	25°C, 10^5Pa
Town gas (12A and 13A)	*49.46*	*MJ/kg NCV*	*15.37*	25°C, 10^5Pa
Town gas (Direct supply of LPG)	*46.43*	*MJ/kg NCV*	*17.66*	25°C, 10^5Pa
(Renewable&recovered energy)				
Black liquor	*11.90*	*MJ/kg NCV*	*(0.00)*	Bone dry with ash
Waste woods	*15.34*	*MJ/kg NCV*	*(0.00)*	Bone dry with ash
Liquid biomass	*27.04*	*MJ/kg NCV*	*(0.00)*	Pure ethanol value

Note: The net (lower) calorific values and corresponding carbon emission factors in Tables 6-2-3 and 6-2-4 are created for comparison and reference. They are not to be used in calculations of energy supply and demand amounts, energy-derived carbon dioxide emissions and so forth.

The standard values to be used for calculations are the gross (higher) calorific values and corresponding carbon emission factors in Tables 6-2-1 and 6-2-2.

6-3. Recommendations

6-3-1. Revising the standard calorific values and carbon emission factors

(1) Adding and removing entries in the main table and the reference value table

I think it will be appropriate to reorganize the current tables of standard calorific values and carbon emission factors to add and remove the following items with a view to reflecting recent changes in energy supply and demand conditions and improving the calculation accuracy of energy-derived carbon dioxide emissions.

New entries in the reference value table:

- Pure butane
- Reformed feedstock oil
- Jet fuel (kerosene type) and Jet fuel (gasoline type)
- Galvanic furnace gas
- Imported natural gas (regasified LNG)
- Gas from water-soluble gas fields, Associated gas from oilfields, and Gas from other fields

Transfer from the reference value table to the main table:

- Receiving end input calorific value of electricity

Transfer from the main table to the reference value table:

- Indigenous produced steam coal

Remove from the reference value table:

- Underground indigenous steam coal and Open pit indigenous steam coal
- Town gas (4A-7C)

(2) Updating values in the main table and the reference value table

In the new tables of standard calorific values and carbon emission factors, the entries in the main table and reference value table subsequent to the effects of the changes described in (1) should be updated to standard calorific values and corresponding carbon emission factors based on the newly calculated gross (higher) calorific values in this paper.

The sample sources and the supporting premises for the calculations from measured values have been made clear for many of the new calculated values, and the new calculated values have been comprehensively calculated. The calorific values and carbon emission factors have been systematically calculated from matching groups of measurement samples. Their validities have been confirmed by comparison with the current standard values, the 2006 IPCC Guidelines and the like. Thus, the new calculated values can be considered to be highly transparent, credible and accurate.

6-3-2. Annual recalculation of energy-derived carbon dioxide emissions from some of the standard calorific values and carbon emission factors

Many of the current standard calorific values and carbon emission factors have been updated at intervals of around five years. However, with a view to improving the calculation accuracy of energy-derived carbon dioxide emissions, entries for which weighted averages can be calculated annually from various published statistics and entries that can be recalculated annually from chemical compositions and physical properties using interpolation and approximation equations should be switched to annual recalculation of the standard calorific values and carbon emission factors, to be used in calculating energy-derived carbon dioxide emissions when possible, even if the standard values that are used are generally fixed.

6-3-3. Aggregated calculation by brand of carbon amounts in crude oil

Although the current carbon amounts in crude oil are calculated by brand for the standard calorific values, the carbon emission factors are all calculated using single values for all crude oil.

With a view to improving the calculation accuracy of energy-derived carbon dioxide emissions, the calculation methods should be switched to methods that aggregate and calculate carbon amounts in crude oil by brand using chemical compositions and physical properties, such as specific gravity by brand according to published statistics, and the interpolation and approximation equations for crude oil identified in this paper.

6-3-4. Introduction and revision of interpolation and approximation equations for calorific values and carbon emission factors

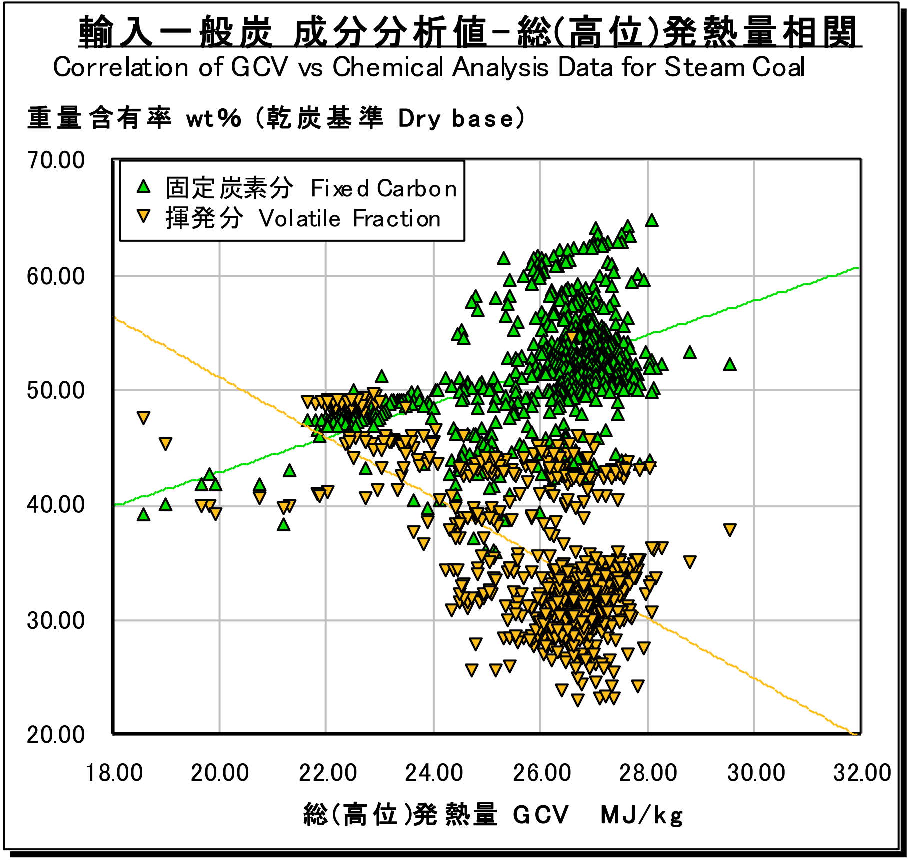
Estimation equations according to JIS K2279 are already used as interpolation and approximation equations for the calorific values of oil and oil products. However, in this paper it was observed in comparison and verification using measurement samples that errors increase and deviations occur with these estimation equations for oil products with densities below 0.8 such as kerosene and jet fuel. It became clear that it is inappropriate to use these estimation equations in such cases.

Moreover, there are currently no estimation equations that can be used for carbon emission factors for oil and oil products. Also, there are no estimation equations that can be used for the calorific values or carbon emission factors of coal.

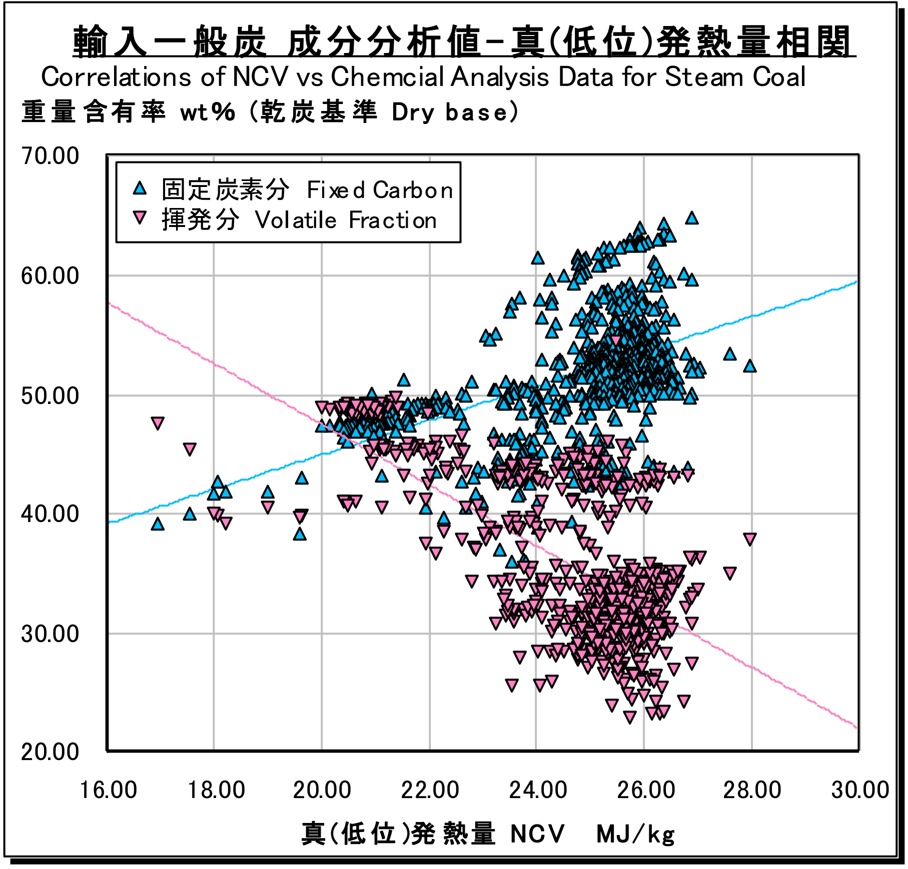
When energy-derived carbon dioxide emissions and the like are being calculated for imported steam coal, crude oil, NGL/condensate, and (liquid) oil products, those of the new interpolation and approximation equations identified in this paper that will enable accurate estimations should be selected and used.

Attached Figures

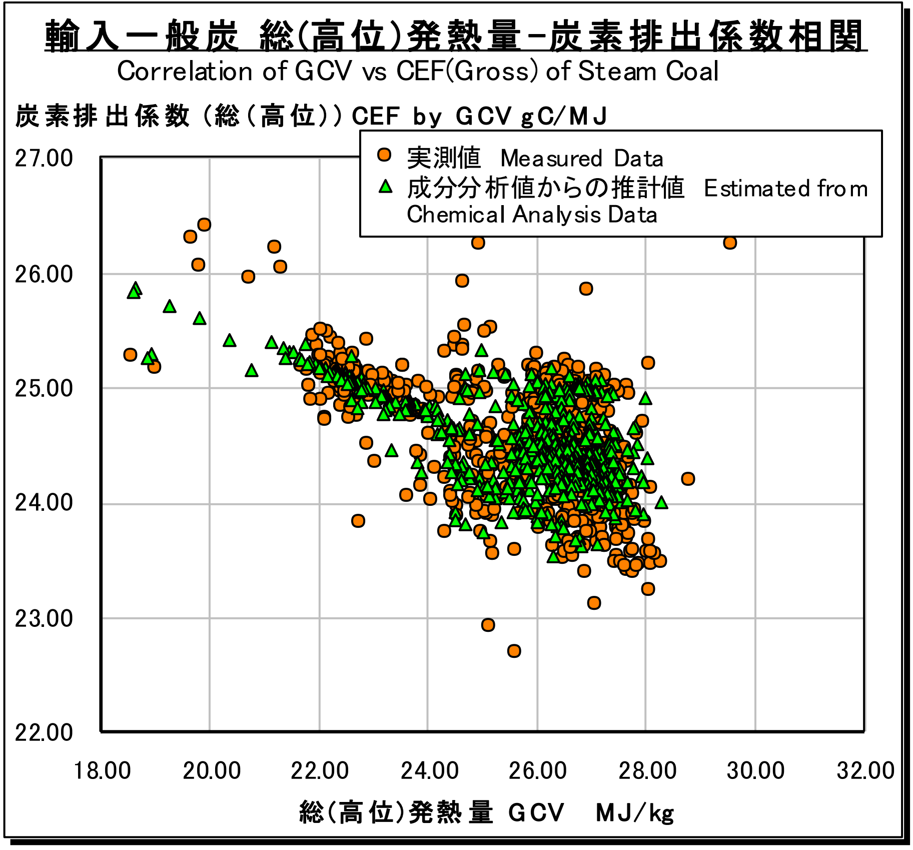
[Fig. 3-1-4-1. Correlation of GCV vs composition and physical properties for imported steam coal]



[Fig. 3-1-4-2. Correlation of NCV vs composition and physical properties for imported steam coal]

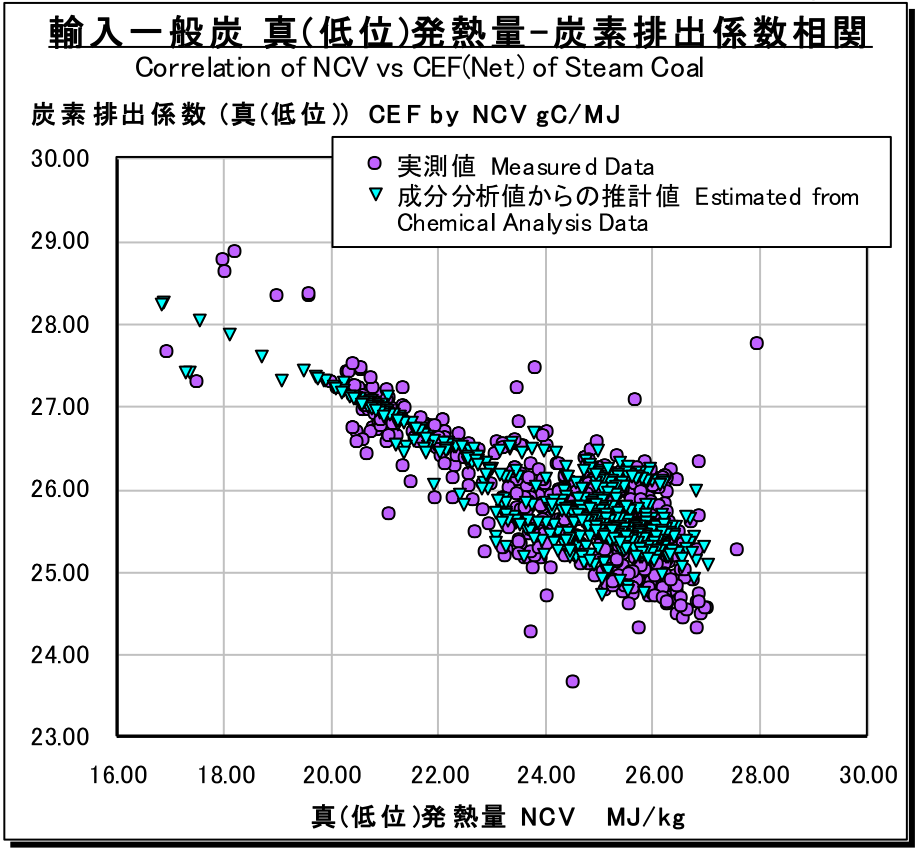


[Fig. 3-1-4-3. Correlation of GCV vs CEF (gross) for imported steam coal]



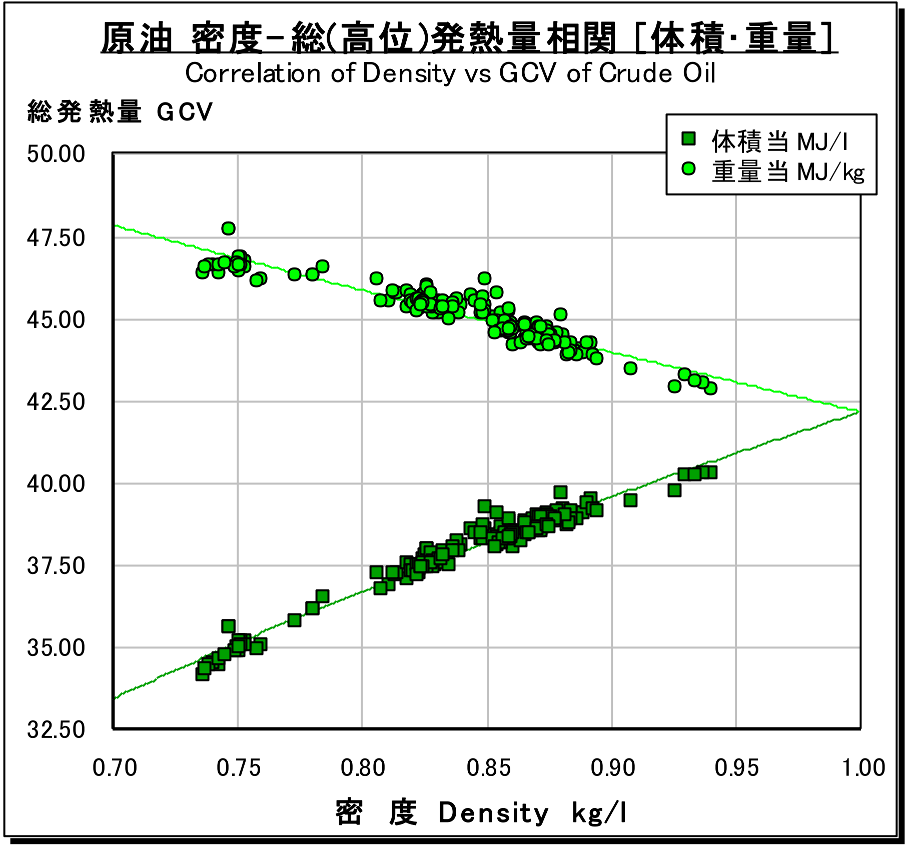
Note: X-Y values are estimation results from equations 3-1-4-1 and 3-1-4-2.

[Fig. 3-1-4-4. Correlation of NCV vs CEF (net) for imported steam coal, including estimated values]

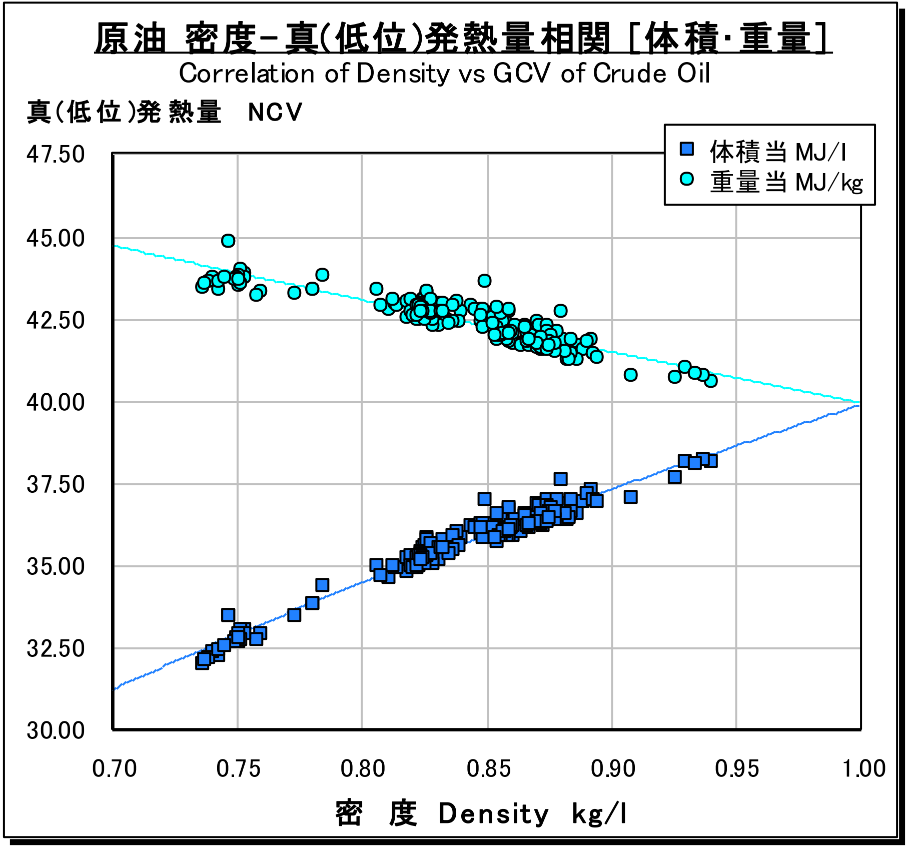


Note: X-Y values are estimation results from equations 3-1-4-4 and 3-1-4-5.

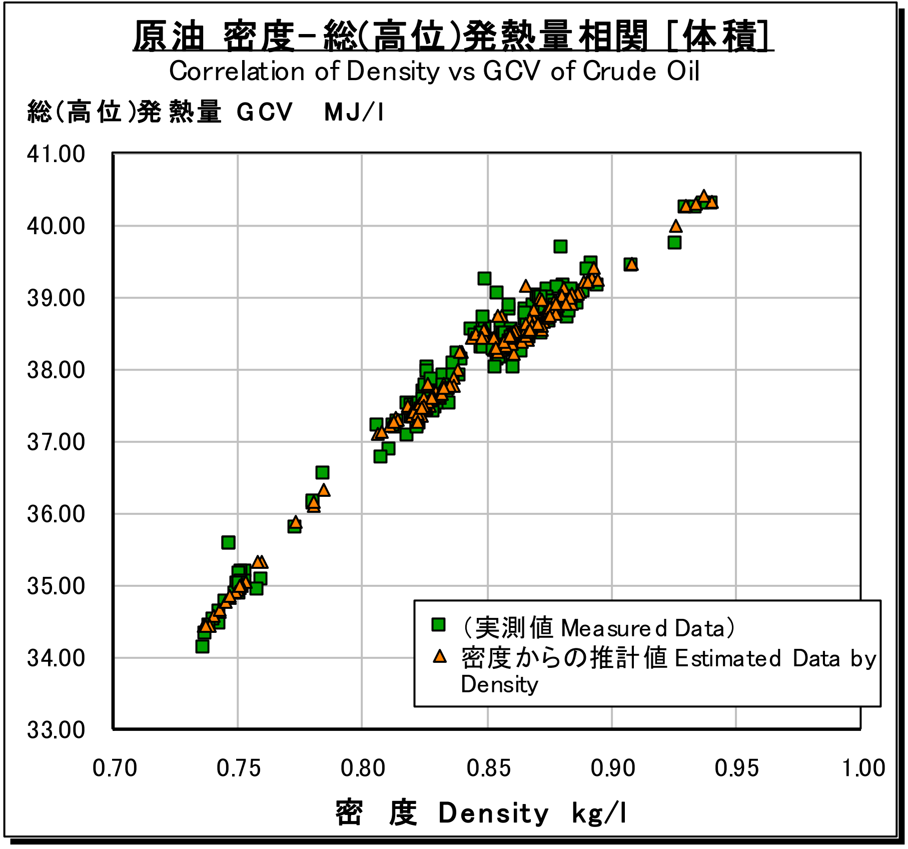
[Fig. 4-1-1-1. Correlation of density vs GCV for crude oil (by volume and by mass)]



[Fig. 4-1-1-2. Correlation of density vs NCV for crude oil (by volume and by mass)]

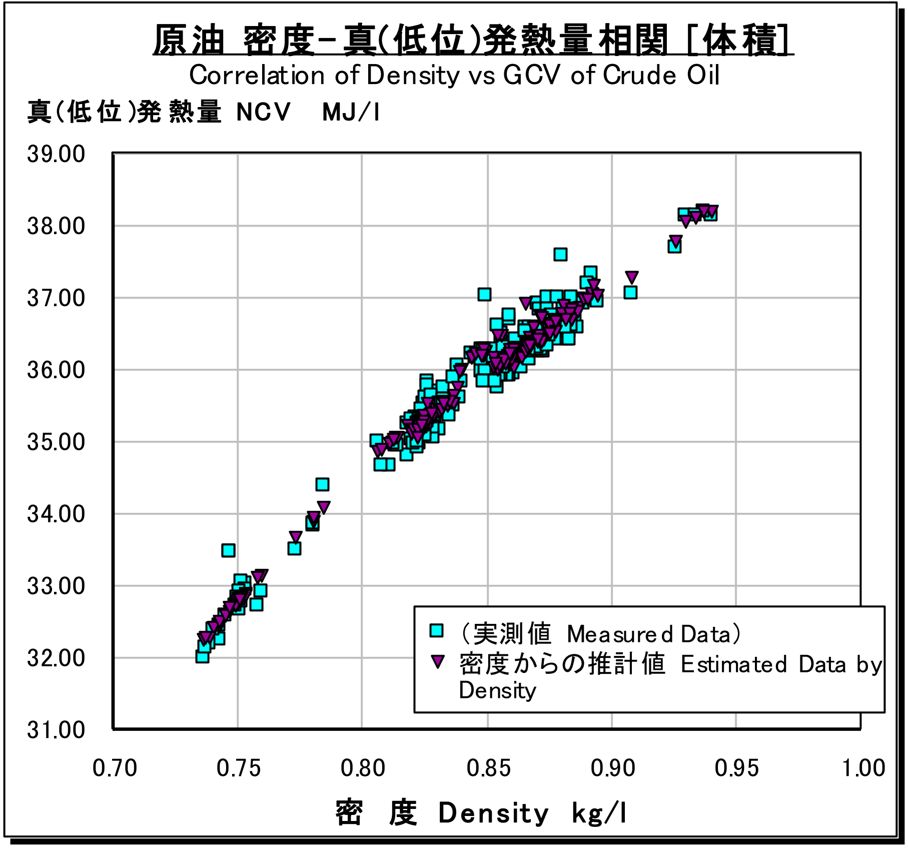


[Fig. 4-1-1-3. Correlation of density vs GCV for crude oil (by volume), including estimated values]



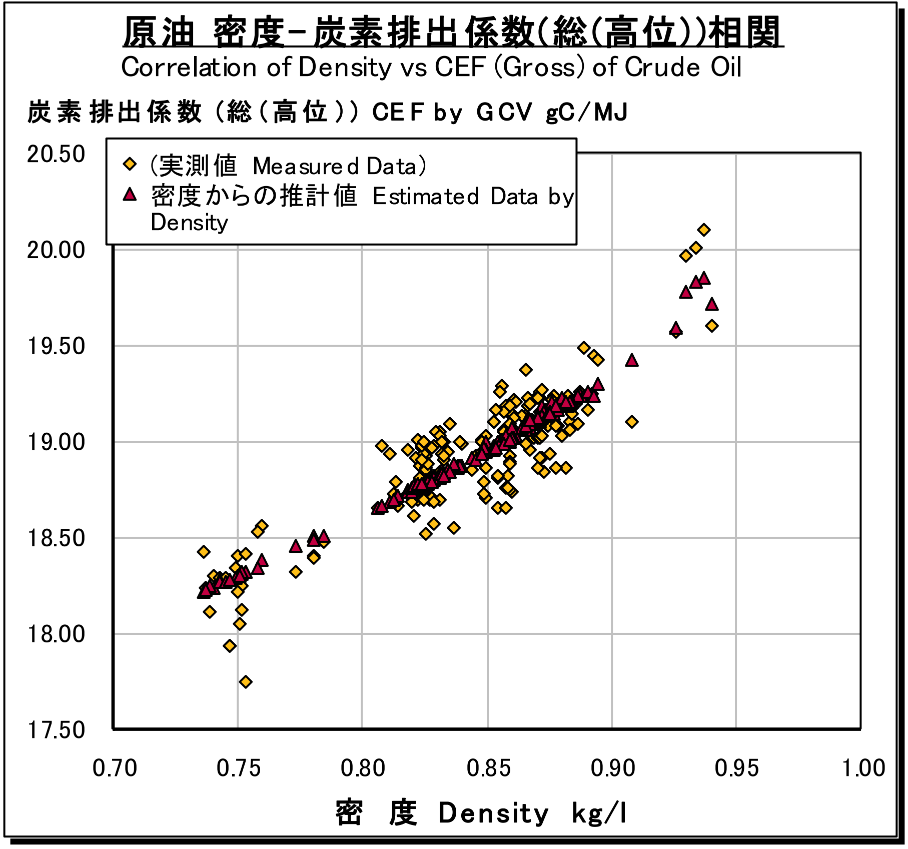
Note: Estimation results from equation 4-1-1-1 are shown.

[Fig. 4-1-1-4. Correlation of density vs NCV for crude oil (by volume), including estimated values]



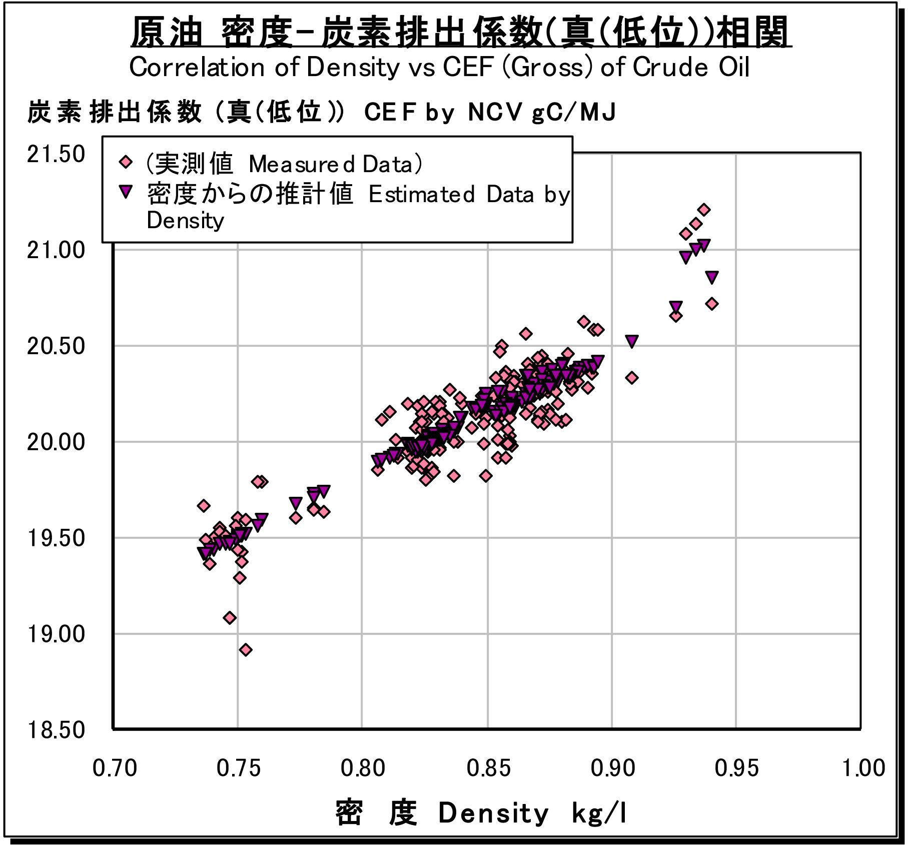
Note: Estimation results from equation 4-1-1-7 are shown.

[Fig. 4-1-1-5. Correlation of density vs CEF (gross) for crude oil, including estimated values]



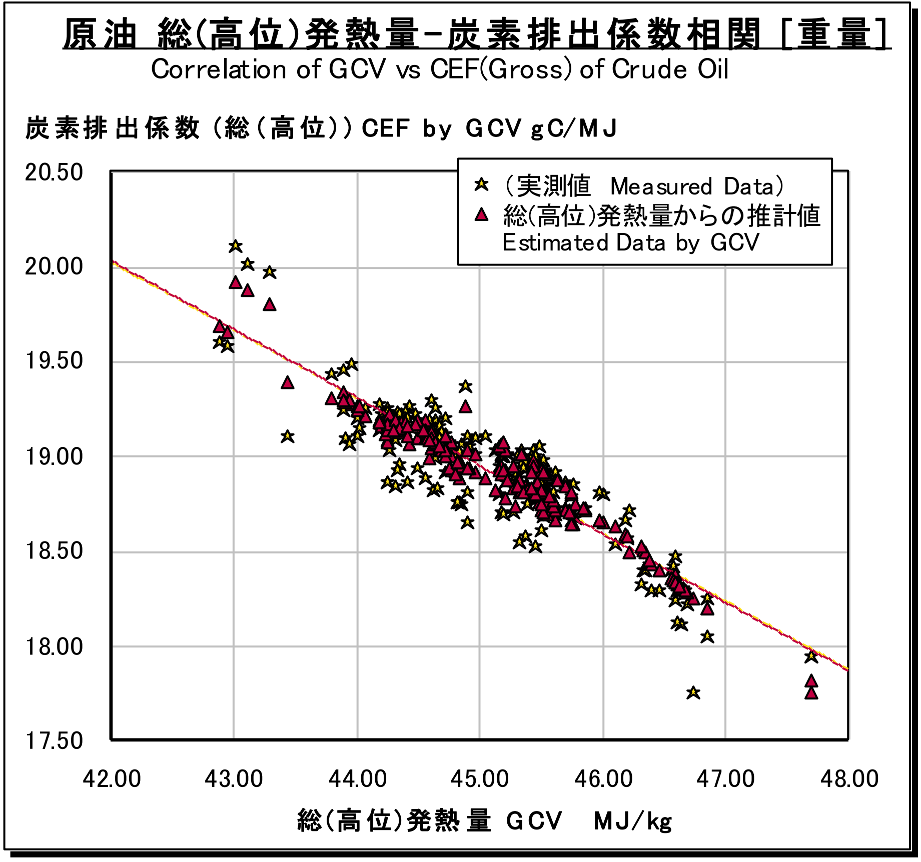
Note: Estimation results from equation 4-1-1-4 are shown.

[Fig. 4-1-1-6. Correlation of density vs CEF (gross) for crude oil, including estimated values]



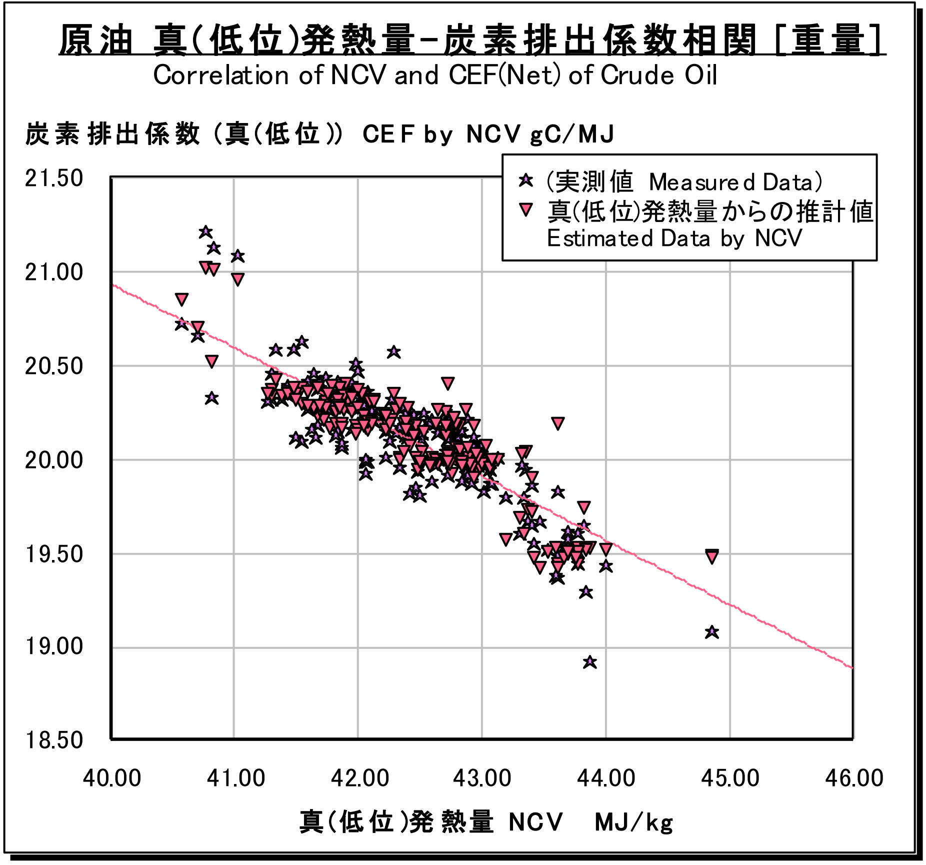
Note: Estimation results from equation 4-1-1-11 are shown.

[Fig. 4-1-1-7. Correlation of GCV vs CEF (gross) for crude oil (by mass), including estimated values]



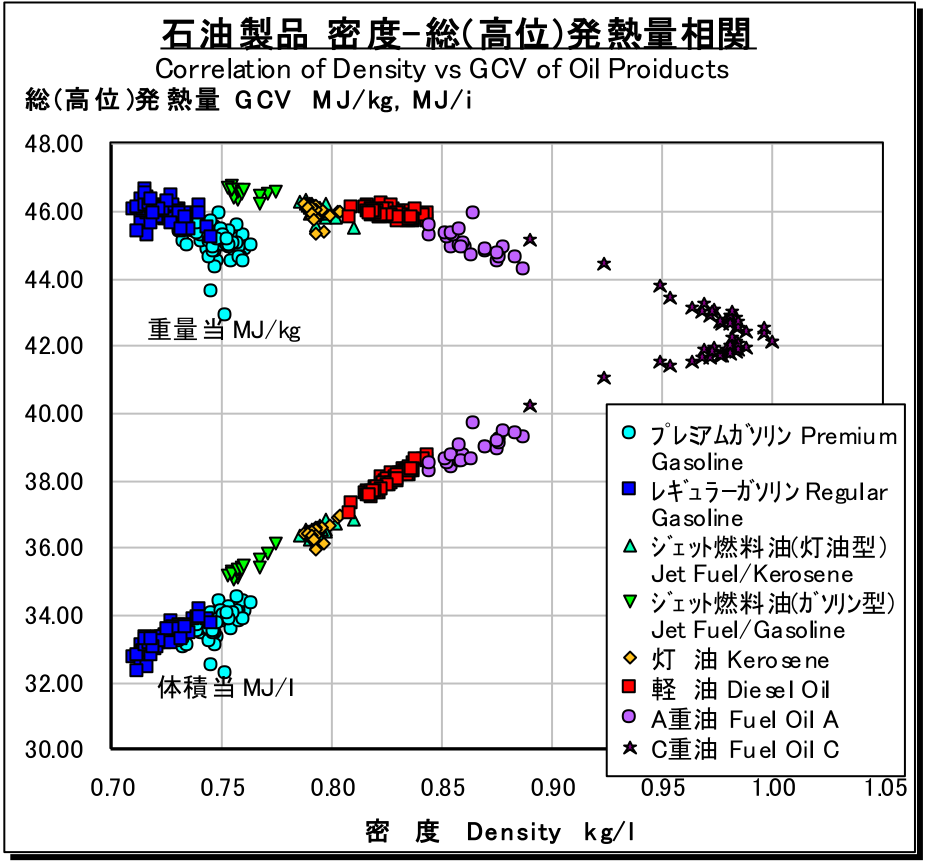
Note: Estimation results from equation 4-1-1-6 are shown.

[Fig. 4-1-1-8. Correlation of NCV vs CEF (net) for crude oil (by mass), including estimated values]

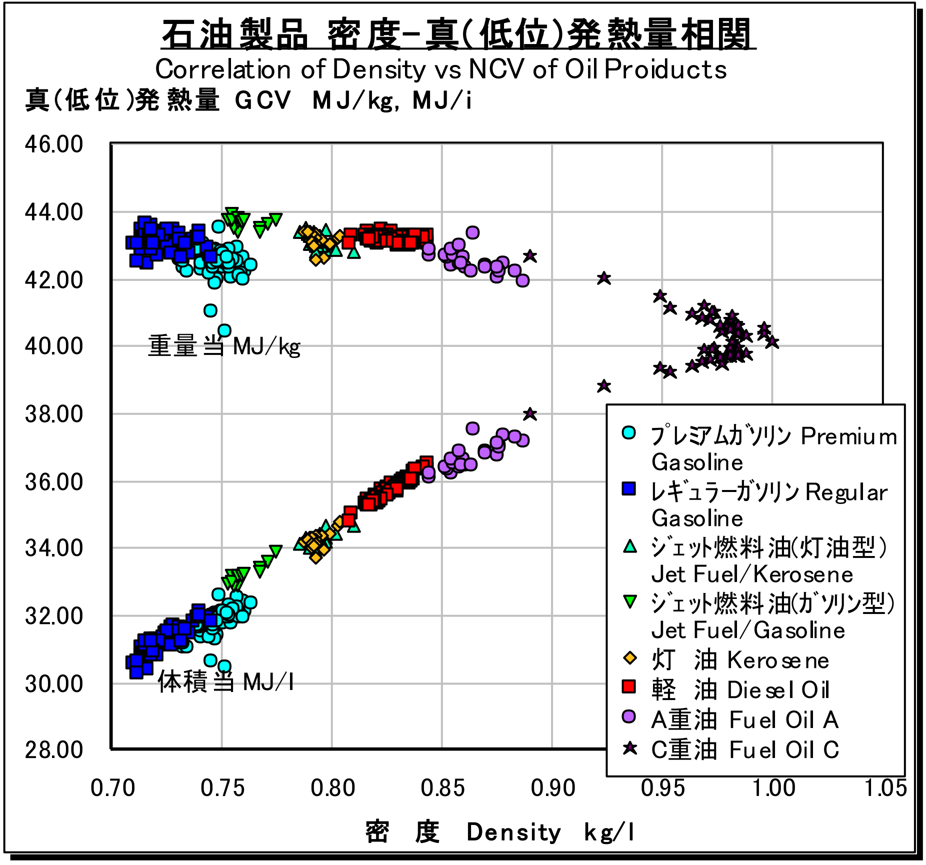


Note: Estimation results from equation 4-1-1-13 are shown.

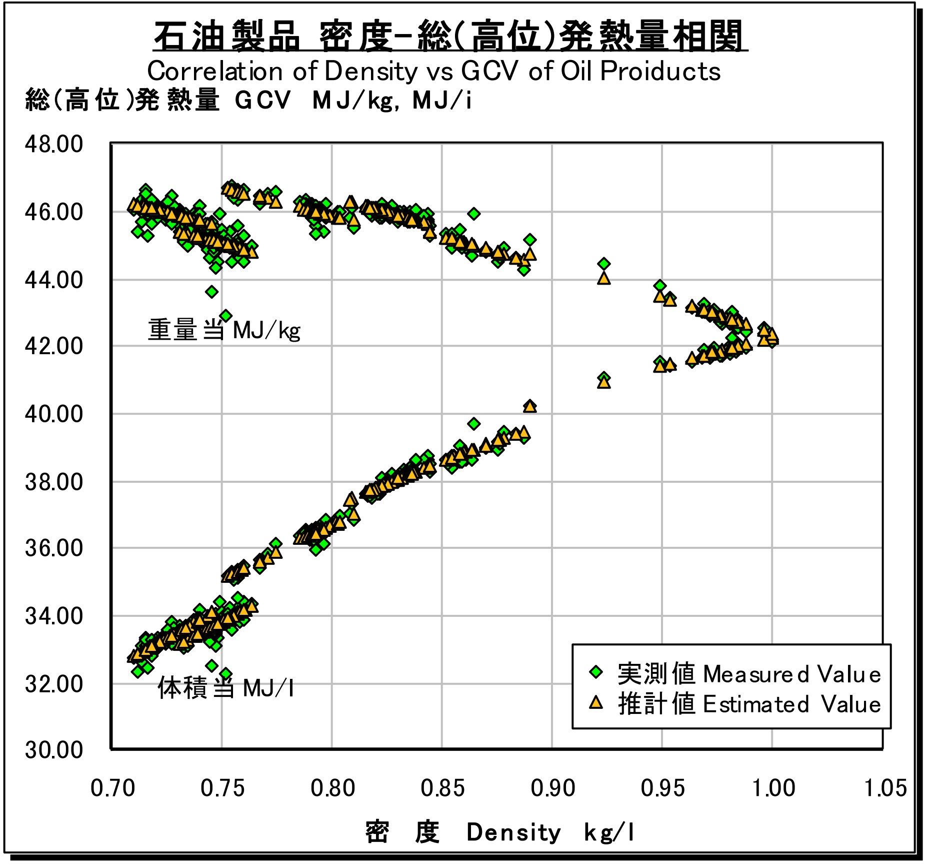
[Fig. 4-2-8-1. Correlation of density vs GCV for oil products]



[Fig. 4-2-8-2. Correlation of density vs NCV for oil products]

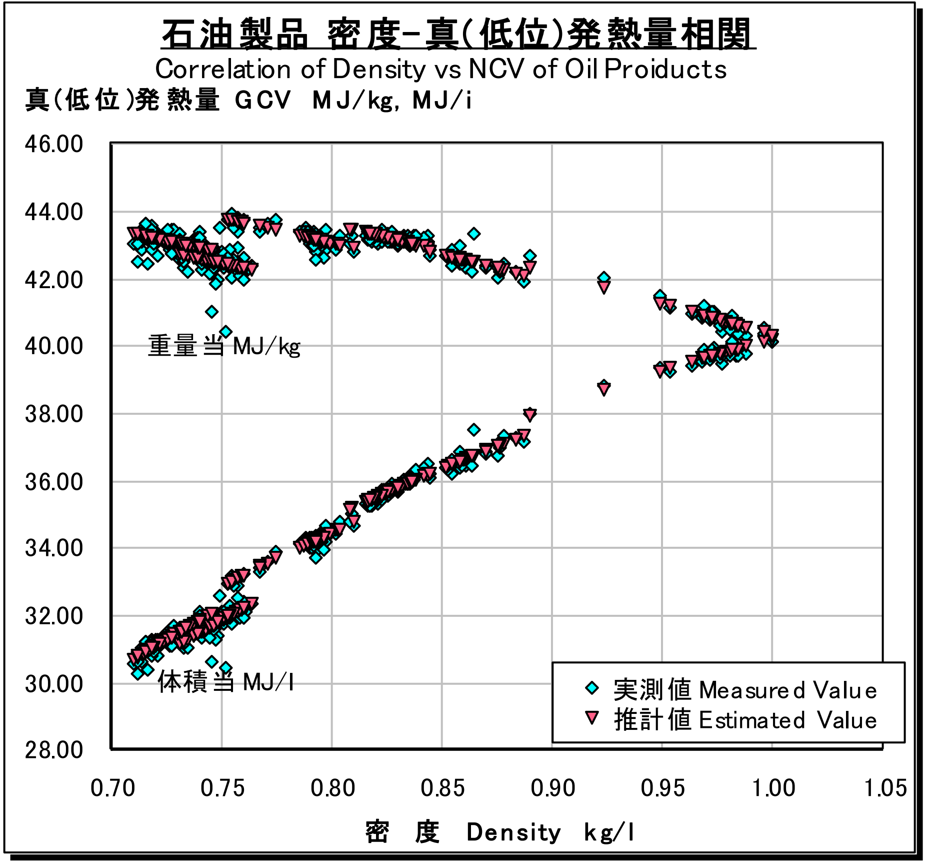


[Fig. 4-2-8-3. Correlation of density vs GCV for oil products, including estimated values]



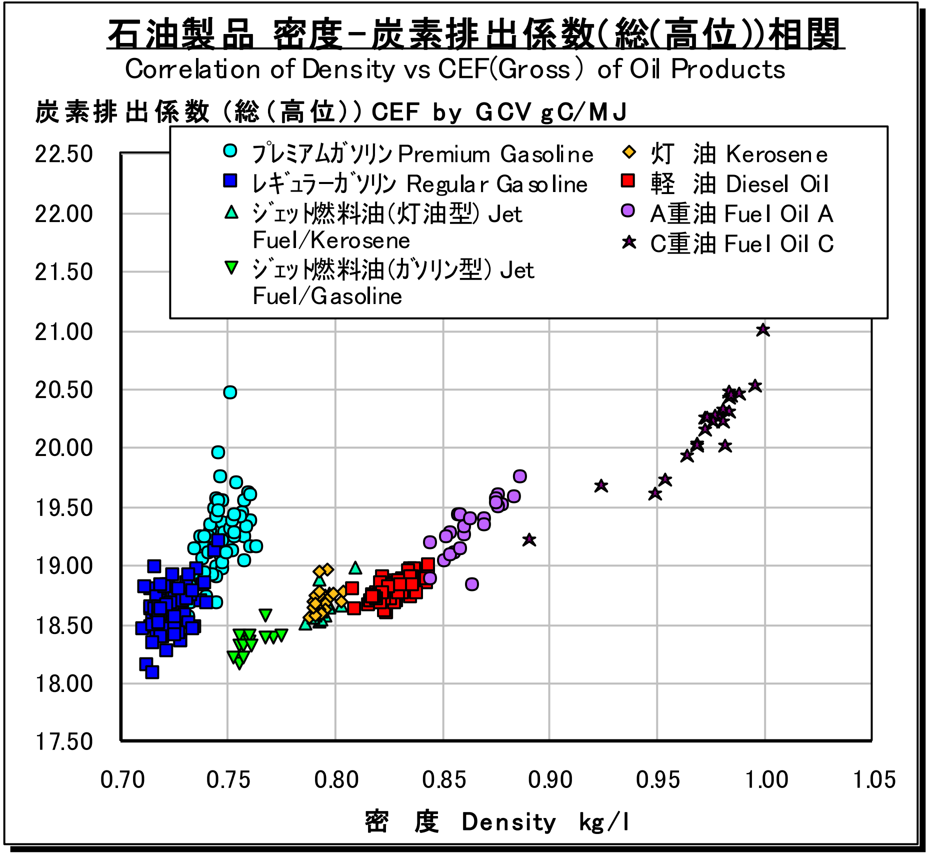
Note: Estimated values are from equations 4-2-8-2 (by volume) and 4-2-8-6 (by mass).

[Fig. 4-2-8-4. Correlation of density vs NCV for oil products, including estimated values]

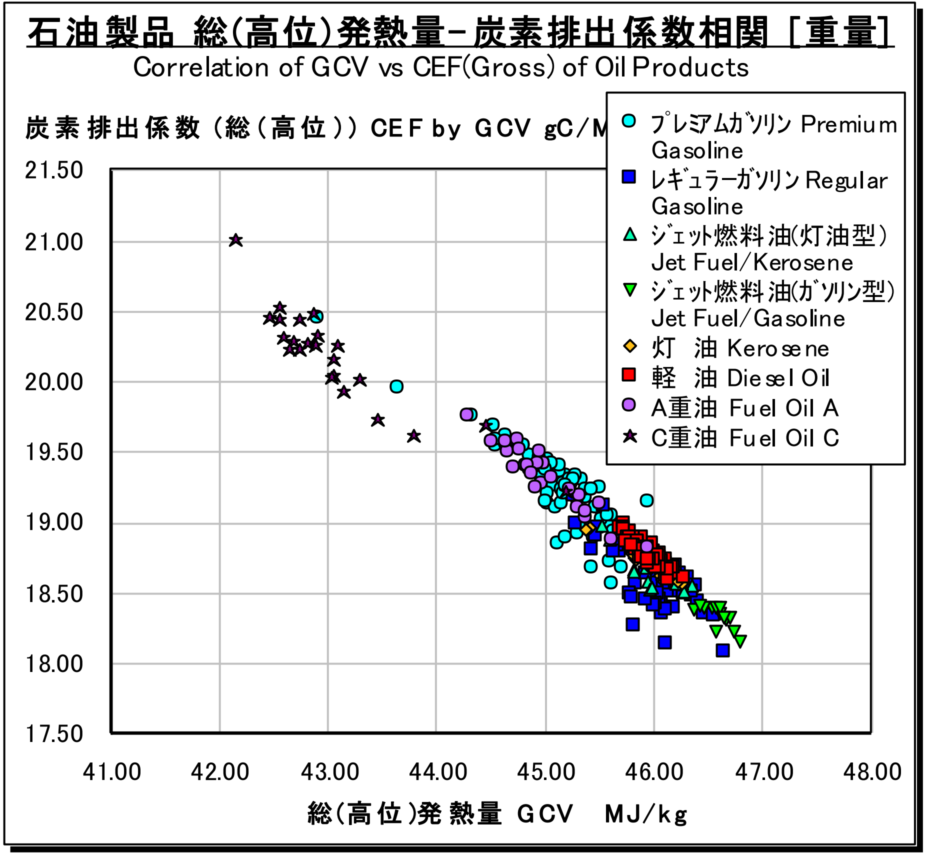


Note: Estimated values are from equations 4-2-8-11 (by volume) and 4-2-8-13 (by mass).

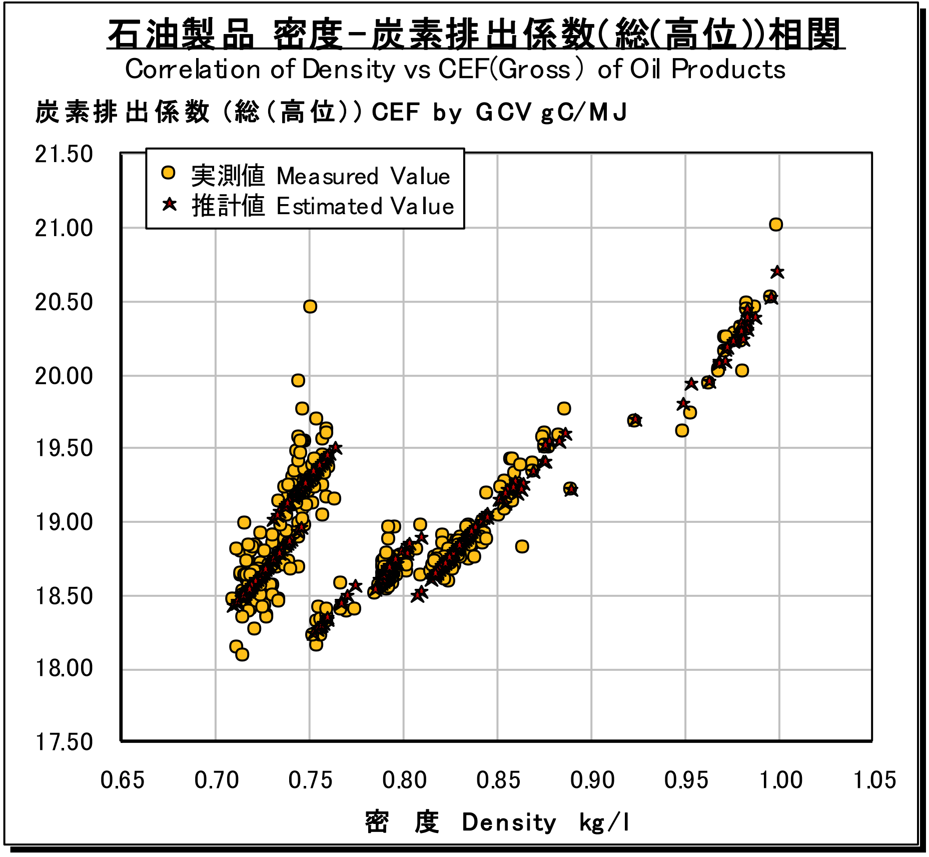
[Fig. 4-2-8-5. Correlation of density vs CEF (gross) for oil products]



[Fig. 4-2-8-6. Correlation of GCV vs CEF (gross) for oil products (by mass)]

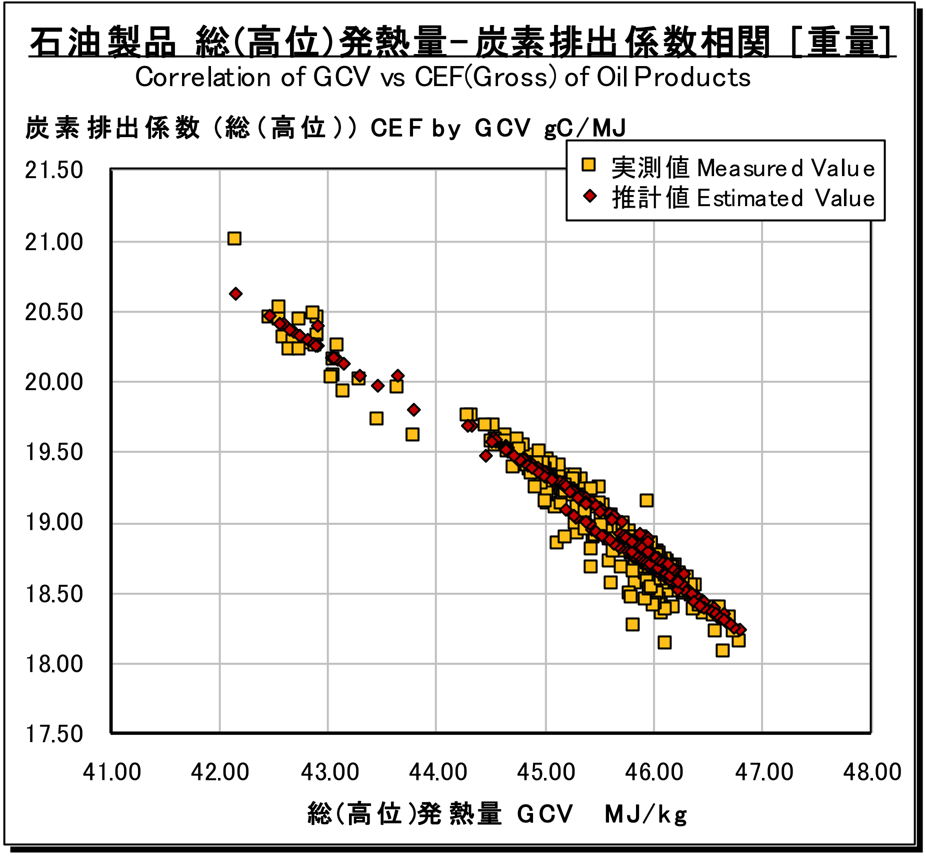


[Fig. 4-2-8-7. Correlation of density vs CEF (gross) for oil products, including estimated values]



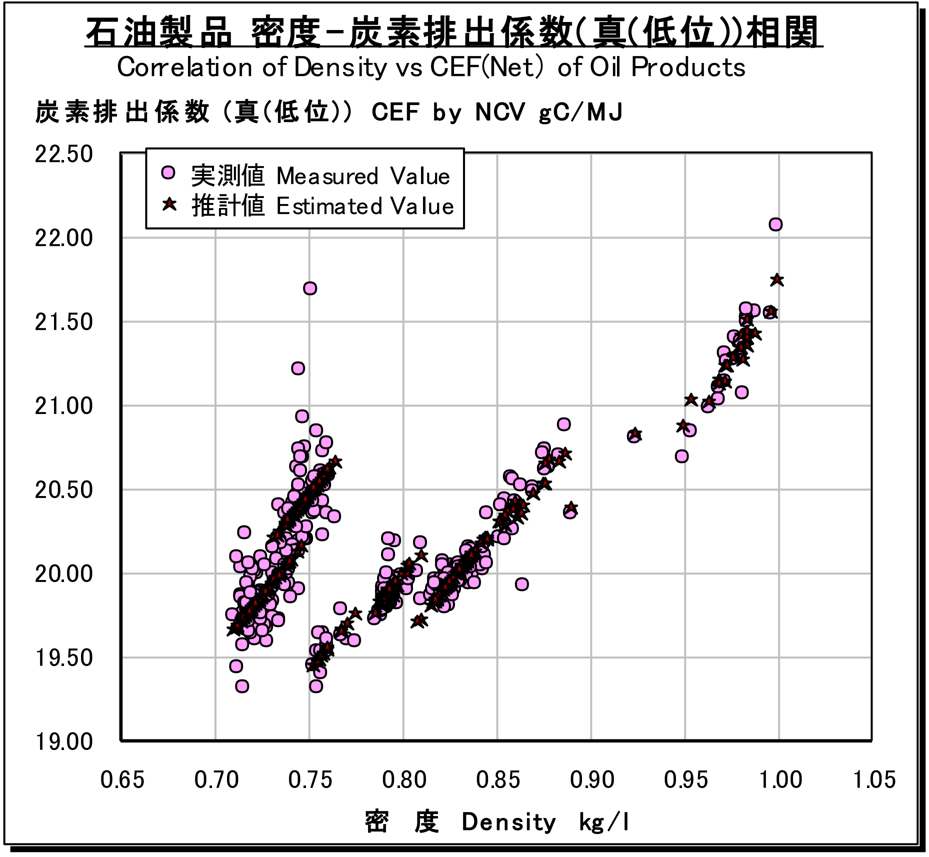
Note: Estimated values are from equation 4-2-8-8.

[Fig. 4-2-8-8. Correlation of GCV vs CEF (gross) for oil products (by mass), including estimated values]



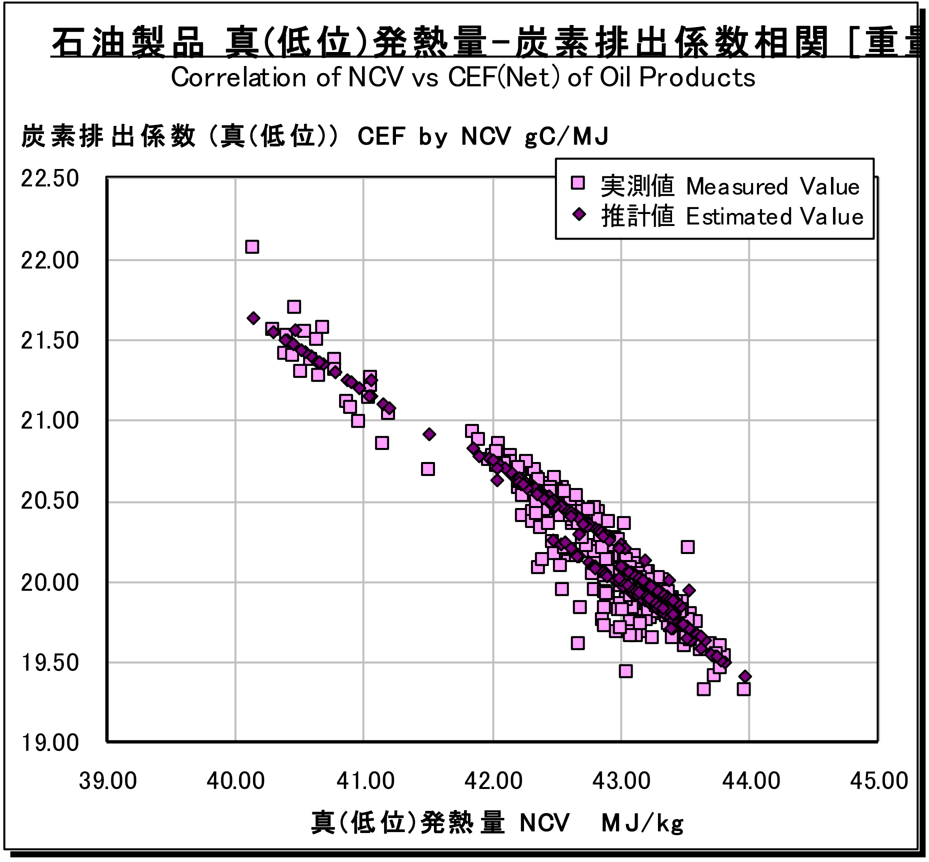
Note: Estimated values are from equation 4-2-8-9.

[Fig. 4-2-8-9. Correlation of density vs CEF (net) for oil products, including estimated values]



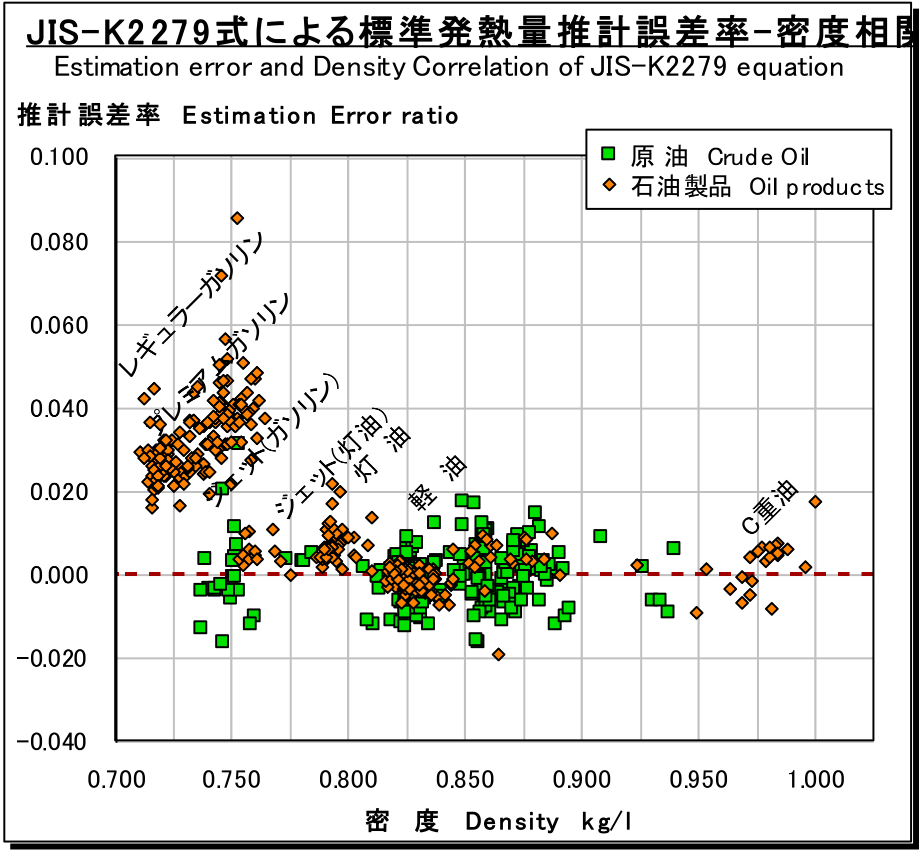
Note: Estimated values are from equation 4-2-8-15.

[Fig. 4-2-8-10. Correlation of NCV vs CEF (net) for oil products (by mass), including estimated values]

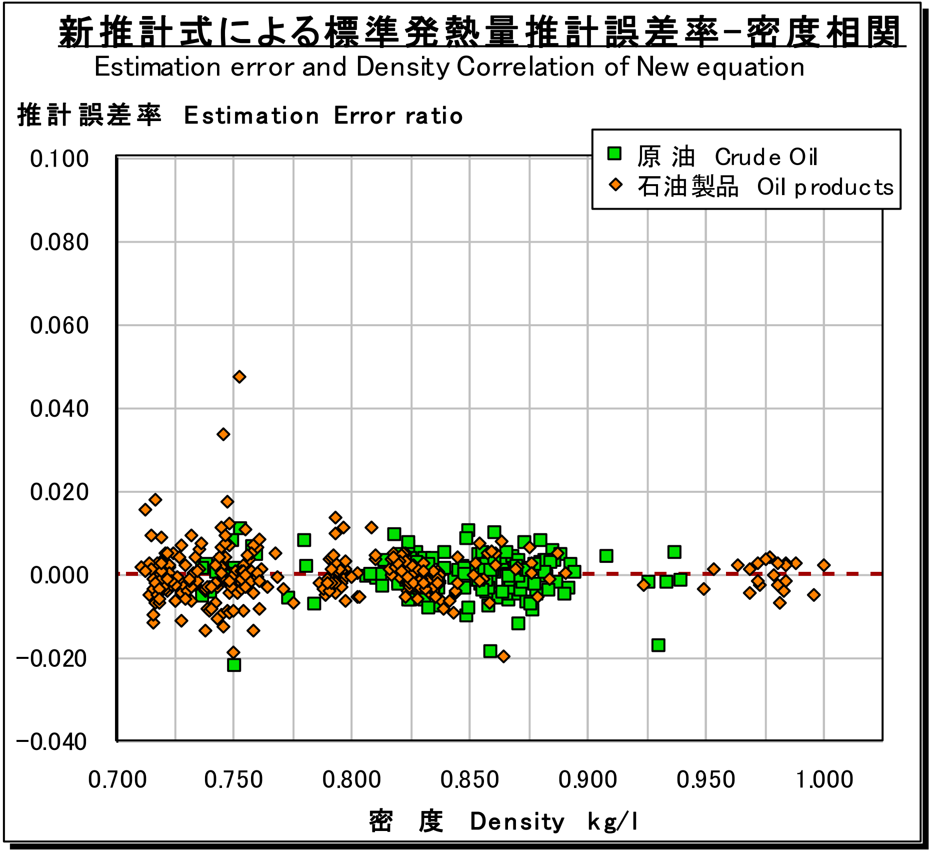


Note: Estimated values are from equation 4-2-8-16.

[Fig. 4-2-8-11. Correlation of estimation errors in standard calorific values from equations in JIS K2279 vs density]

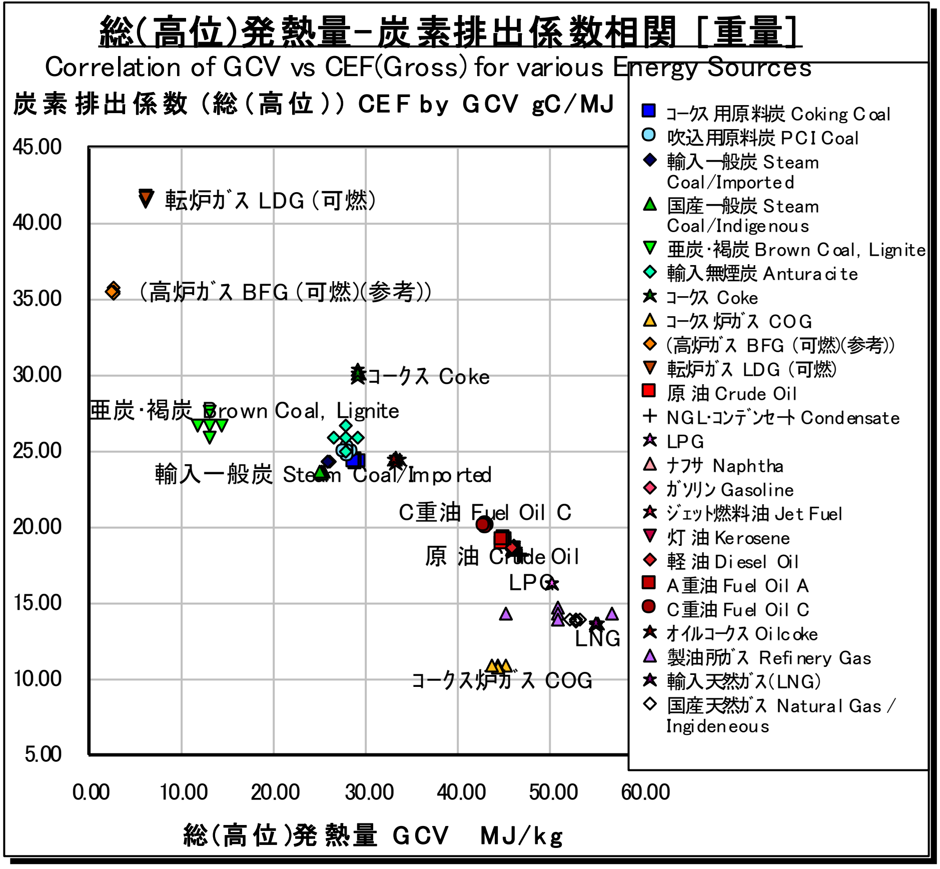


[Fig. 4-2-8-12. Correlation of estimation errors in standard calorific values from new estimation equations vs density]



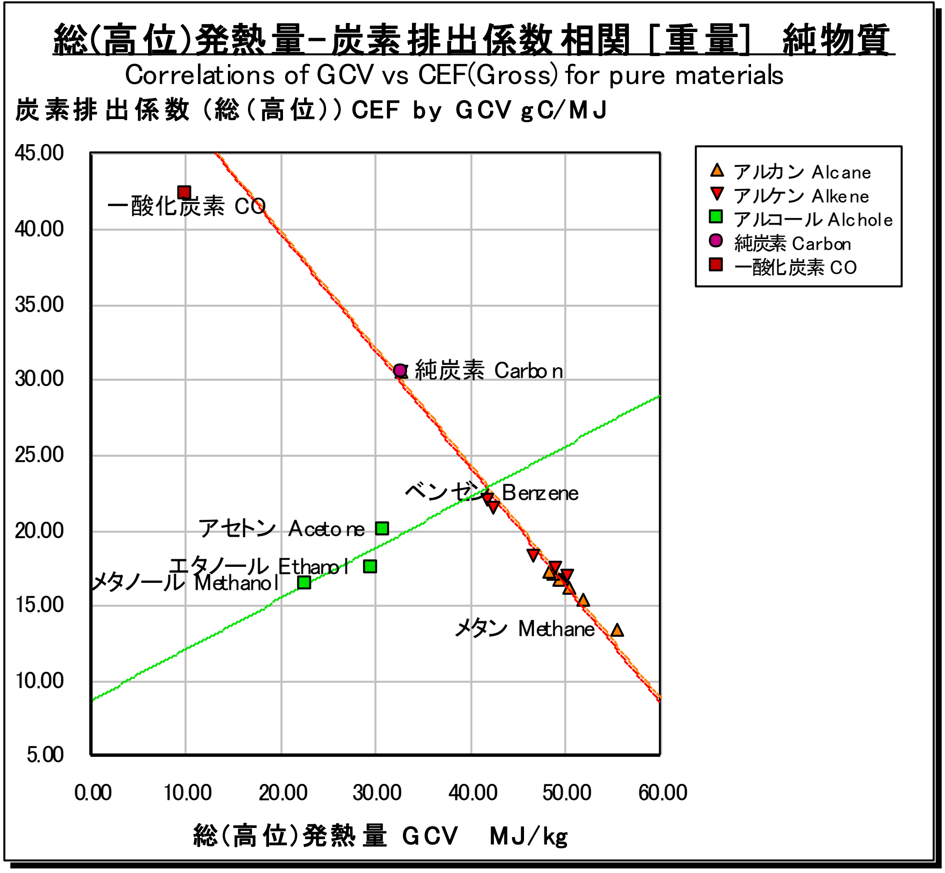
Note: Calculated by dividing differences between measured values and estimated values from equations 4-1-1-1 and 4-2-8-1 by the measured values.

[Fig. 6-2-1-1. Correlation of GCV vs CEF (gross) (by mass): (1) all fuels]

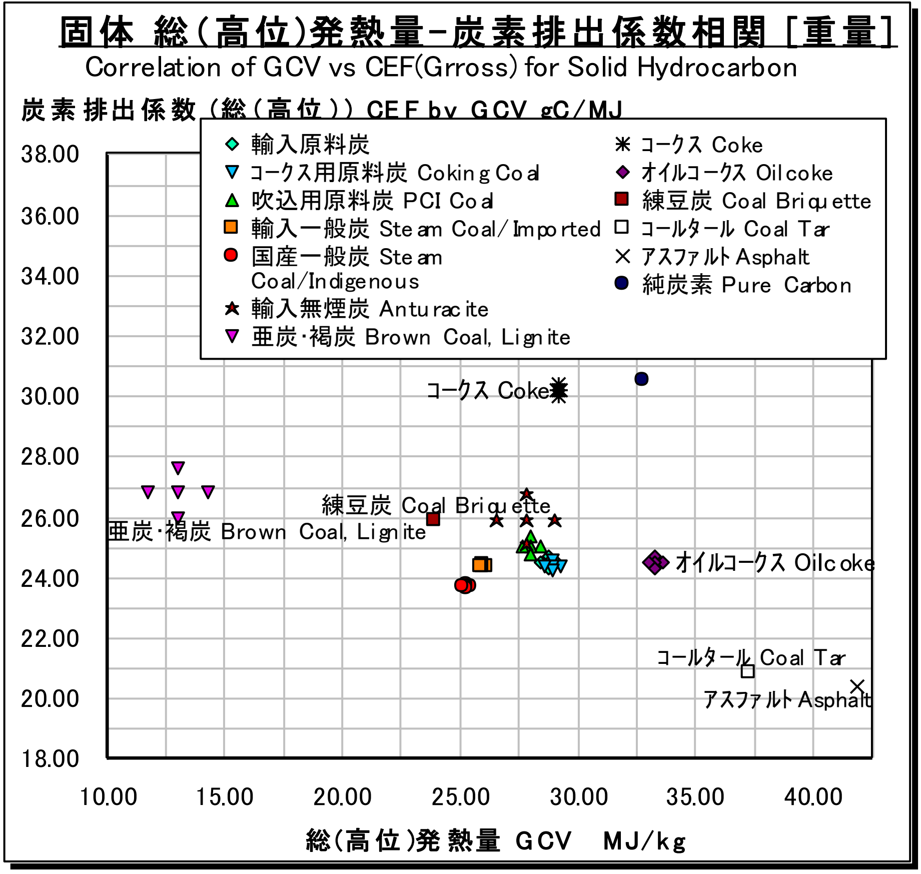


Note: The five marks for each plot represent the confidence interval upper and lower limits and mean value of the gross (higher) calorific value, and the upper and lower limits of the carbon emission factor. The same applies below.

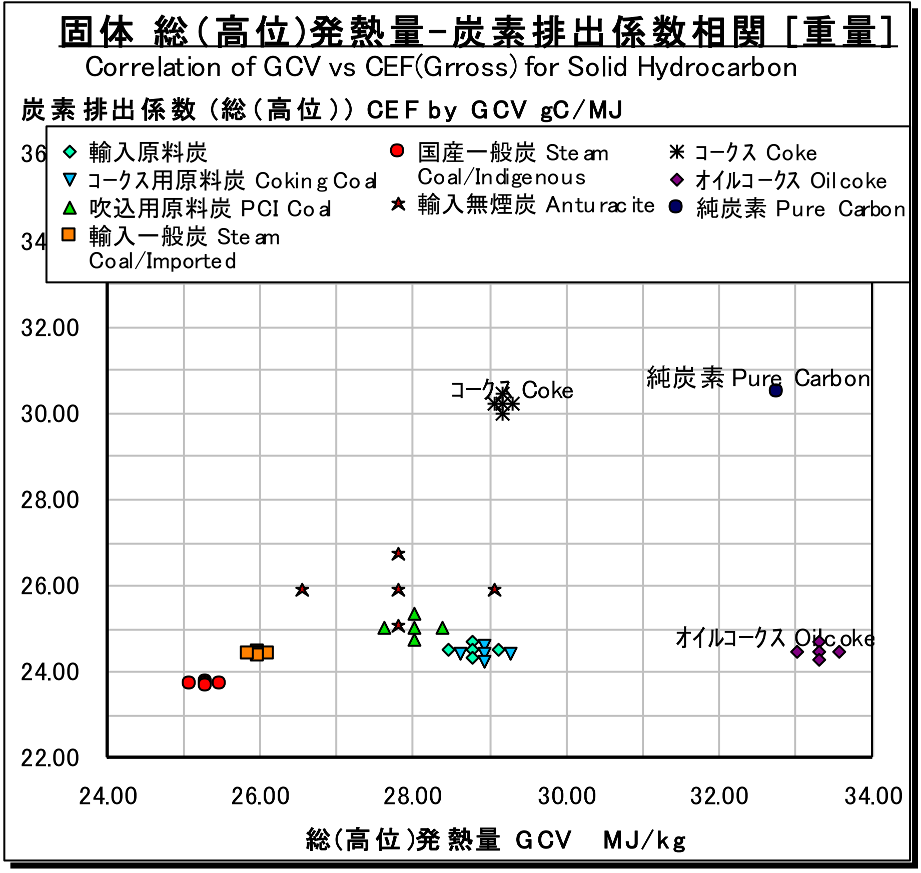
[Fig. 6-2-1-2. Correlation of GCV vs CEF (gross) (by mass): (2) pure materials]



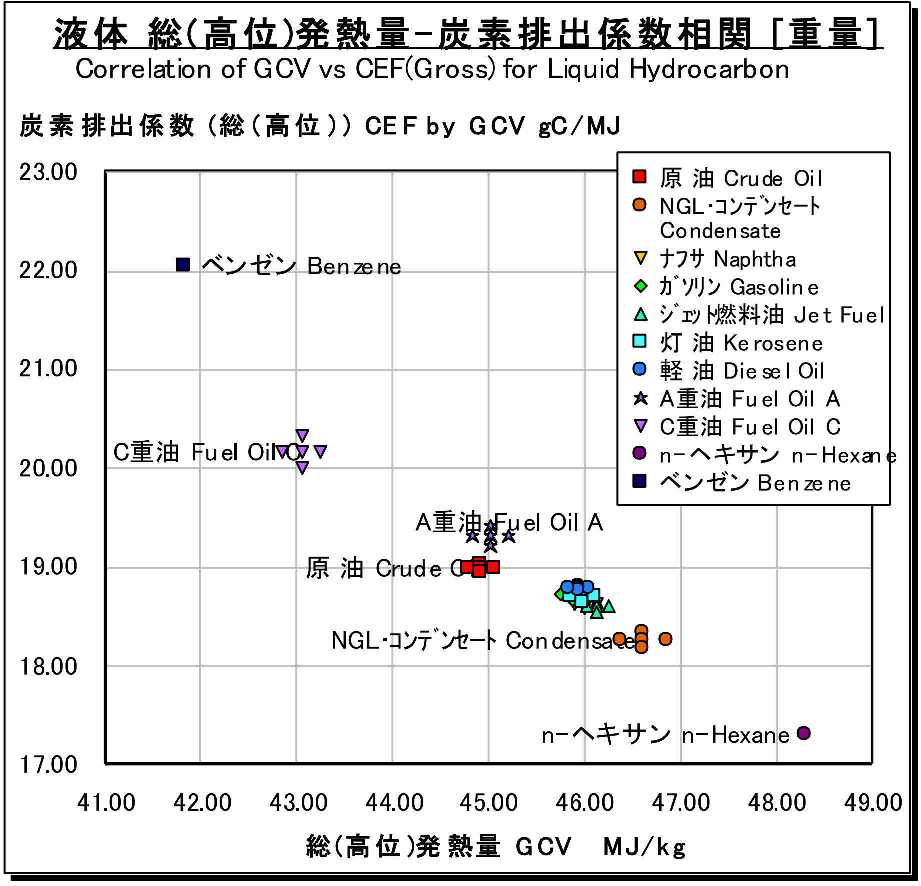
[Fig. 6-2-1-3. Correlation of GCV vs CEF (gross) for solids (by mass): (1) all fuels]



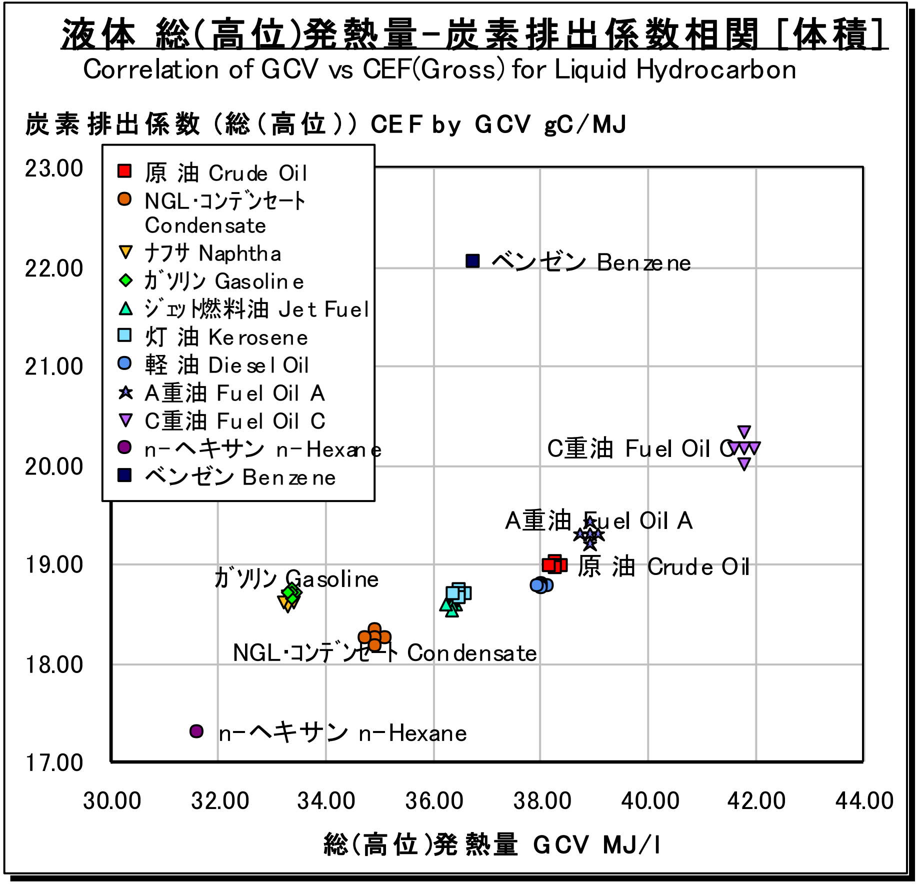
[Fig. 6-2-1-4. Correlation of GCV vs CEF (gross) (by mass) for solids: (2) major fuels]



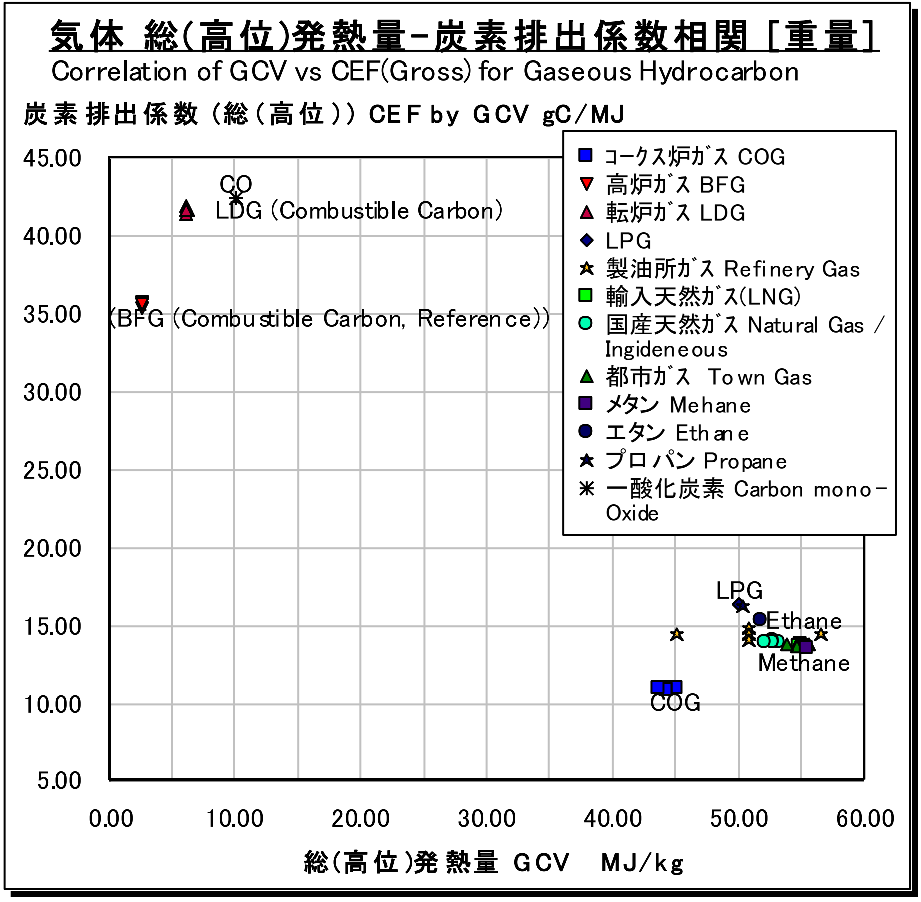
[Fig. 6-2-1-5. Correlation of GCV vs CEF (gross) for liquids (by mass)]



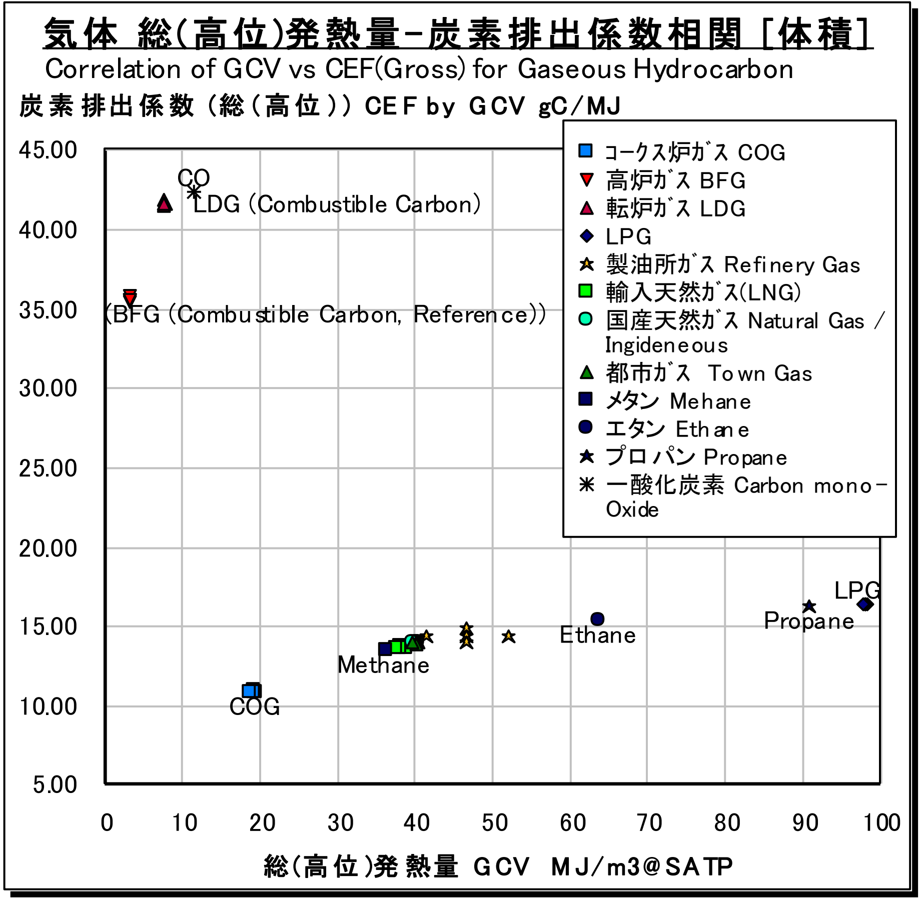
[Fig. 6-2-1-6. Correlation of GCV vs CEF (gross) for liquids (by volume)]



[Fig. 6-2-1-7. Correlation of GCV vs CEF (gross) for gases (by mass)]



[Fig. 6-2-1-8. Correlation of GCV vs CEF (gross) for gases (by volume)]



ADDENDA

Addendum 1. Calculating Calorific Values and Carbon Emission Factors of Pure Materials from the Standard Enthalpy of Formation

1. Standard enthalpy of formation and calorific value

1-1. Meaning of the term "standard enthalpy of formation"

The standard enthalpy of formation is a value in physical chemistry representing the total heat energy of the reactions required to form one mole of a material under standard conditions from units of constituent elements such as carbon and hydrogen under the same standard conditions.

Reaction heat depends on temperature and pressure; so, these conditions must be specified. The standard conditions that are used are the standard ambient temperature and pressure (SATP), which are 25°C (298.15 K) and 10^5 Pa.

The unit of the standard enthalpy of formation is $\mathrm{kJ \cdot mol^{-1}}$ and the symbol is $\Delta_t H^\circ$.

Standard enthalpies of formation under SATP for a range of materials are listed in the physical chemistry section of the Chronological Scientific Tables*28 published annually by the National Astronomical Observatory of Japan. These values are used in this paper.

1-2. Estimating calorific values from differences in standard enthalpy of formation: gross (higher) calorific value and net (lower) calorific value

A calorific value is the combustion heat that is released when a material completely reacts by combustion under SATP and its combustion products are returned to SATP. Therefore, the calorific value for 1 mole of a material is equal to the difference in total values of standard enthalpy of formation before and after the combustion reaction, i.e., between the material and its combustion products.

If the combustion product when hydrogen combusts is water (as liquid), the result of this calculation is the gross (higher) calorific value; the calculated result if the combustion product is steam (as gas) is the net (lower) calorific value. The difference between the two is the latent heat when water becomes steam at 100°C (40.660 $\mathrm{kJ \cdot mol^{-1}}$ at 100°C).

As a specific case, if 1 mole of ethanol (C_2H_6O) completely combusts, 2 moles of carbon dioxide (CO_2) and 3 moles of water or steam (H_2O) are produced. Therefore, the gross (higher) calorific value and net (lower) calorific value of ethanol under SATP can be calculated as shown below, using the standard enthalpy of formation of the respective materials and their molecular weights.

Refer to Addenda Table 1-1-2 for results calculated for various organic materials by the same method.

[Addenda Table 1-1-1. Calculation of theoretical calorific values of ethanol (C_2H_6O) using the standard enthalpy of formation]

@SATP	Molecular weight Mw($\mathrm{g \cdot mol^{-1}}$)	Standard enthalpy of formation ΔH° ($\mathrm{kJ \cdot mol^{-1}}$)
Ethanol (C_2H_6O)	46.068	-277.00
Oxygen (O_2)	31.998	0 (a single-element compound)
Carbon dioxide (CO_2)	44.010	-393.50
Water (liquid, H_2O)	18.015	-285.83
Steam (gas, H_2O)	18.015	-245.17 (= -285.83+40.66)

$$\begin{array}{llllll} C_2H_6O & + 3\,O_2 & \rightarrow & 2\,CO_2 & + 3\,H_2O & + Q \\ -277.00 & + 3*0 & = & 2*-393.50 & + 3*-285.83 & + \underline{1367.49}\ \mathrm{kJ \cdot mol^{-1}}\ \text{(water produced)} \\ -277.00 & + 3*0 & = & 2*-393.50 & + 3*-245.17 & + \underline{1245.54}\ \mathrm{kJ \cdot mol^{-1}}\ \text{(steam produced)} \end{array}$$

Gross (higher) calorific value (GCV)	By mass: 29.68 MJ/kg (=1367.49/46.068)	By volume: 23.42 MJ/l (d°=0.789)
Net (lower) calorific value (NCV)	By mass: *27.04* MJ/kg (=1245.54/46.068)	By volume: *21.33* MJ/l

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*28 The Chronological Scientific Tables list, in addition to the standard enthalpy of formation $\Delta_t H^\circ$, the Gibbs energy ${}_tG^\circ$ and the standard entropy S. However, the standard enthalpy of formation $\Delta_t H^\circ$ is used for estimating calorific values.

2. Carbon content and carbon emission factors

2-1. Carbon content and gross (higher) and net (lower) carbon emission factors

The carbon content is the content by mass of carbon contained in a material.

A carbon emission factor is defined as the amount of carbon contained in a unit amount (of the original unit) of a material divided by the calorific value when the unit amount of the material is completely combusted, and is equal to the carbon content divided by the calorific value per unit mass. The carbon emission factor represents the amount of carbon in carbon dioxide that is produced in relation to the calorific value when 1 kg of the material (or 1 L or 1 m^3 at SATP) completely combusts. The carbon emission factor is given in gC/MJ.

It is important to note that carbon emission factors are distinguished for different calorific values; there are gross (higher) and net (lower) carbon emission factors. As a specific case, while ethanol (C_2H_6O) has a carbon content of 0.521, two carbon emission factors are calculated, as shown below.

In Japan, the calorific values that are usually used are the gross (higher) calorific values and the original units are defined for respective energy sources in the "Tables of standard calorific values" from ANRE/METI. Therefore, the carbon emission factors that are used conform to those definitions. However, in many cases the IPCC uniformly uses net (lower) calorific values and net (lower) carbon emission factors. Therefore, particular care must be taken when the numeric value is shown only for single carbon emission factors.

[Addenda Table 1-2-1. Differences between gross (higher) and net (lower) carbon emission factors of ethanol (C_2H_6O)]

Carbon content of ethanol (C_2H_6O): 0.521 (= 2*12.01/(2*12.01 + 6*1.008 + 1*15.999))

Ethanol	Calorific values (MJ/kg or MJ/l)			Carbon emission factors (gC/MJ)	
Gross (higher) by mass	29.68	MJ/kg	GCV	17.57	> Gross (higher) carbon emission factor CEF-G
Gross (higher) by volume	23.42	MJ/l	GCV	17.57	
Net (lower) by mass	*27.04*	MJ/kg	NCV	*19.29*	> Net (lower) carbon emission factor CEF-N
Net (lower) by volume	*21.33*	MJ/l	NCV	*19.29*	

2-2. Estimation of carbon dioxide emissions

Using consumption (combustion) amounts of a material and the standard calorific values and carbon emission factors, carbon dioxide emissions can be calculated by using energy consumption amounts as shown below.

The result is the same as the result of simply multiplying a weight of the material by its carbon content; for a pure material, the same result is obtained by either method. However, the carbon dioxide emissions of pure materials are rarely calculated. In order to carry out calculations for mixtures that contain impurities, such as coal or fuel oil C, corrections and conversions must be applied to find energy consumption amounts, after which the corresponding carbon dioxide emissions can be calculated.

[Addenda Expression 1-2-1. Calculating carbon dioxide emissions using standard calorific values and carbon emission factors]

$$EC = X * GCV$$

$$CDE = EC * CEF * 3.664$$

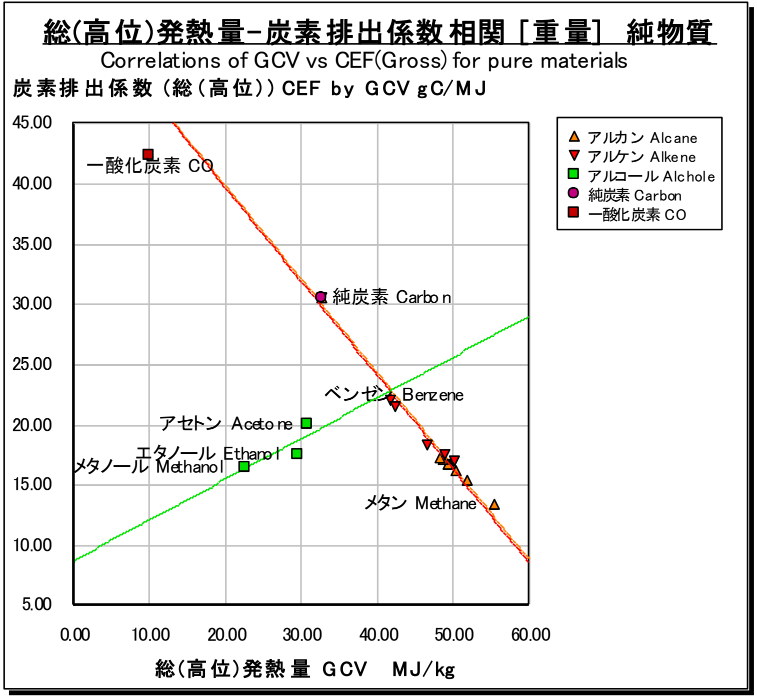
CDE	Carbon dioxide emissions (kg)
EC	Fuel consumption (gross (higher)) (MJ)
X	Amount of material consumed (combusted) (kg, l, m^3@SATP)
GCV	Standard calorific value (gross (higher)) (MJ/kg or MJ/l or MJ/m^3@SATP)
CEF	Carbon emission factor (corresponding to the standard calorific value) (gC/MJ)
"3.664"	Carbon-to-carbon dioxide conversion factor (= 44.010/12.011, the ratio of their molecular weights)

[Addenda Table 1-1-2. Theoretical calorific values and carbon emission factors of various organic materials calculated using the standard enthalpy of formation]

Material/theoretical value	**Gross (higher) calorific value**			**Corresponding carbon emission factor**	Net (lower) calorific value			Corresponding carbon emission factors
	GCV @SATP			CEF-G	NCV @SATP			CEF-N
(Unit)	**MJ/kg**	**MJ/l**	**MJ/m^3**	**gC/MJ (Gross)**	MJ/kg	MJ/l	MJ/m^3	gC/MJ (Net)
Methane	**55.50**		**36.39**	**13.49**	*50.43*		*33.07*	*14.85*
Ethane	**51.87**		**63.76**	**15.40**	*47.82*		*58.77*	*16.71*
Propane	**50.35**		**90.74**	**16.23**	*46.66*		*84.09*	*17.51*
n-butane	**49.51**		**117.62**	**16.70**	*46.01*		*109.31*	*17.96*
i-butane	**49.36**		**117.27**	**16.75**	*45.86*		*108.96*	*18.02*
n-pentane	**48.64**		**143.44**	**17.11**	*45.26*		*133.47*	*18.39*
n-hexane	**48.31**	**31.63**	**170.16**	**17.31**	*45.01*	*29.47*	*158.53*	*18.58*
Ethylene	**50.30**		**57.67**	**17.02**	*47.40*		*54.35*	*18.07*
Propylene	**48.92**		**84.14**	**17.50**	*46.02*		*79.15*	*18.61*
Cyclohexane	**46.58**	**36.28**	**160.22**	**18.38**	*43.68*	*34.02*	*150.25*	*19.60*
Benzene	**41.83**	**36.77**	**133.56**	**22.05**	*40.27*	*35.40*	*128.57*	*22.91*
Toluene	**42.43**	**36.79**	**159.81**	**21.50**	*40.67*	*35.26*	*153.16*	*22.44*
Acetone	**30.82**	**24.38**	**73.16**	**20.13**	*28.72*	*22.72*	*68.17*	*21.60*
Methanol	**22.68**	**17.98**	**29.70**	**16.53**	*20.14*	*15.97*	*26.37*	*18.61*
Ethanol	**29.68**	**23.42**	**55.89**	**17.57**	*27.04*	*21.33*	*50.91*	*19.29*
(Reference value)								
Hydrogen	**141.79**		**11.68**	**0.00**	*121.62*		*10.02*	*0.00*
Carbon (non-specific)	**32.76**			**30.52**	*32.76*			*30.52*
Carbon monoxide	**10.10**		**11.57**	**42.44**	*10.10*		*11.57*	*42.44*
Hydrogen sulfide	**16.50**		**22.98**	**0.00**	*15.30*		*21.32*	*0.00*
Sulfur	**9.26**			**0.00**	*9.26*			*0.00*

Note: See Addendum 1, section 1-2 for calculation procedure and calculations from standard enthalpies of formation and molecular weights of materials. Empty spaces in the table indicate states of the materials (liquid or gas) that are not obtained at standard ambient temperature and pressure (SATP: 25°C (298.15 K), 10^5 Pa)

[Addenda Fig. 1-1-1. Correlations of gross (higher) calorific value vs carbon emission factor (by mass) for pure materials (Fig. 6-2-1-2 in the body of the paper)]



Addendum 2. Methods for Comparing and Verifying the New Calculated Calorific Values and Carbon Emission Factors against the Current Standard Values and the 2006 IPCC Guidelines

1. Basic approach to comparison and verification; interpretation of results

1-1. Using 95% confidence intervals for comparison and verification

A statistical sample comprised of n samples forms a distribution with a mean value $\overline{\mu}$ and a standard deviation $\overline{\sigma}$. If the distribution of samples does not fail a normality test and can be treated as a normal distribution, the upper and lower limits of a 95% confidence interval about the mean value $\overline{\mu}$ can be calculated as follows, using a standard error $\overline{\sigma} * n^{-0.5}$ and a t-distribution critical value $t_{0.05}$.

95% confidence interval upper limit: $\overline{\mu} + t_{0.05} * \overline{\sigma} * n^{-0.5}$

95% confidence interval lower limit: $\overline{\mu} - t_{0.05} * \overline{\sigma} * n^{-0.5}$

$t_{0.05} = \mathrm{tinv}(0.05, n-1);\ n \rightarrow \infty \Rightarrow t_{0.05} = 1.960$

The significance of the upper and lower limits of the 95% confidence interval is that they are suitable for estimating a range of possible values of an actual mean value μ of the parent data set from the mean value $\overline{\mu}$ and error calculated from the samples.

Therefore, if the new standard calorific values and carbon emission factors calculated in this paper are treated as values of $\overline{\mu}$, the validity and consistency of the new standard calorific values and carbon emission factors with respect to the calorific values and carbon emission factors being checked against may be verified to some extent by comparison and verification: determining whether the calorific values and carbon emission factors being checked against fall within the 95% confidence intervals of the new standard calorific values and carbon emission factors; where they fall outside, determining how far outside they fall; and so forth.

1-2. Caution for comparison and verification using 95% confidence intervals

In this comparison and verification, the standard temperature and pressure for the new gross (higher) calorific values and corresponding carbon emission factors differ from the standard temperatures and pressures for the current standard calorific values and carbon emission factors. Therefore, the comparison and verification must be carried out with due consideration for divergences due to differences in temperature and pressure, particularly in regard to gases and liquids, or appropriate corrections should be applied to the current standard values if possible.

1-3. Interpreting the results when large divergences are found in comparison and verification

There is no guarantee that the current standard calorific values and carbon emission factors or the 2006 IPCC Guidelines are closer to true values than the new calculated standard calorific values and carbon emission factors. Therefore, when there is a large divergence in the results of comparison, this must only be understood to mean that it is possible that one or both of the current standard values and the new calculated values is not valid.

However, where the new calculated standard calorific values and carbon emission factors diverge greatly to either the large side or the small side relative to both the current standard calorific values and carbon emission factors and the 2006 IPCC Guidelines, then unless there is a particular credible reason for this divergence, it is very likely that the new calculated standard calorific values and carbon emission factors are not valid.

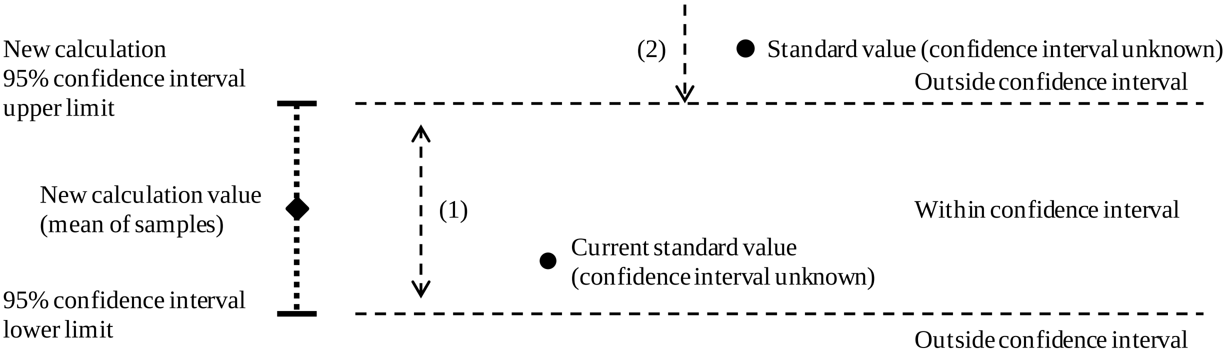
2. Gross (higher) calorific value and corresponding carbon emission factor

2-1. Comparison and verification of gross (higher) calorific values and corresponding carbon emission factors against the current standard values

The new gross (higher) calorific values and corresponding carbon emission factors calculated in this paper correspond to, respectively, the current standard calorific values and actual calorific values and the current carbon emission factors. Because 95% confidence intervals are not available for the current standard values, the comparison and verification determines whether or not the current standard values are within the ranges of the upper and lower limits of the 95% confidence intervals of the new calculated values.

Basically, where the current standard values are within the 95% confidence intervals of the new gross (higher) calorific values and corresponding carbon emission factors, the current values and new values can be considered equal and it is very likely that both the values are broadly valid.

[Addenda Fig. 2-2-1. Conceptual Scheme for the comparison and verification of gross (higher) calorific values and corresponding carbon emission factors against current standard values]


New calculation
95% confidence interval
upper limit
(2)
Standard value (confidence interval unknown)
Outside confidence interval
New calculation value
(mean of samples)
(1)
Within confidence interval
Current standard value
(confidence interval unknown)
95% confidence interval
lower limit
Outside confidence interval

(1) Current standard value within 95% confidence interval of new calculated value: High likelihood that both values are broadly valid

(2) Current standard value outside 95% confidence interval of new calculated value: Likelihood that one of the values is not valid

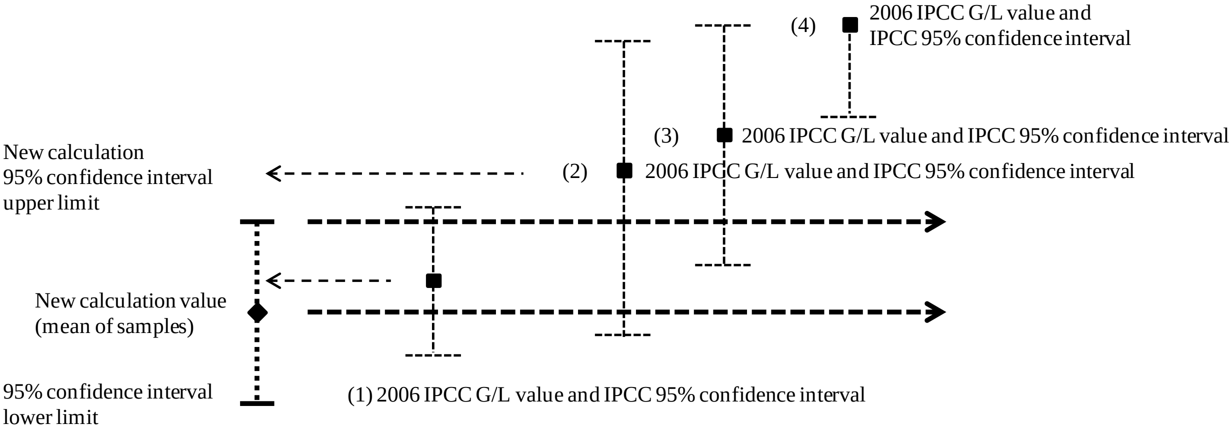
3. Net (lower) calorific value and corresponding carbon emission factor

3-1. Comparison and verification of net (lower) calorific values and corresponding carbon emission factors against the 2006 IPCC Guidelines

The new net (lower) calorific values and corresponding carbon emission factors calculated in this paper correspond to the respective values in the 2006 IPCC Guidelines. In the 2006 IPCC Guidelines, 95% confidence intervals are shown for most of the major energy sources. Therefore, the comparison and verification determines whether or not the 2006 IPCC Guidelines values and the new calculated values are within the ranges of the upper and lower limits of one another's 95% confidence intervals, and whether or not the 95% confidence intervals overlap.

Basically, where the 95% confidence intervals greatly overlap, such as when the two values are within one another's 95% confidence intervals, the current values and new values can be considered equal and it is very likely that both the values are broadly valid.

[Addenda Fig. 2-3-1. Conceptual scheme for the comparison and verification of net (lower) calorific values and corresponding carbon emission factors against the 2006 IPCC Guidelines (G/L)]


(4)
2006 IPCC G/L value and
IPCC 95% confidence interval
(3)
2006 IPCC G/L value and IPCC 95% confidence interval
New calculation
95% confidence interval
upper limit
(2)
2006 IPCC G/L value and IPCC 95% confidence interval
New calculation value
(mean of samples)
95% confidence interval
lower limit
(1) 2006 IPCC G/L value and IPCC 95% confidence interval

(1) 2006 IPCC Guidelines value and new calculated value within one another's 95% confidence interval: High likelihood that both values are broadly valid
→ Within IPCC 95% confidence interval; within new calculation 95% confidence interval

(2) One of 2006 IPCC Guidelines value and new calculated value within the other's 95% confidence interval: Likelihood that both values are valid
→ Within IPCC 95% confidence interval; outside new calculation 95% confidence interval or
Outside IPCC 95% confidence interval; within new calculation 95% confidence interval

(3) Both values outside the other's 95% confidence interval but the confidence intervals overlap: Likelihood that one of the values is not valid
→ Outside IPCC interval; outside new calculation 95% confidence interval; some overlap of confidence intervals

(4) Both values outside the other's 95% confidence interval and the confidence intervals do not overlap: High likelihood that one of the values is not valid
→ Outside IPCC 95% confidence interval; outside new calculation 95% confidence interval; no overlap of confidence intervals

Addendum 3. Types of Coal and Measurement Standards Including Dry Coal and Wet Coal; Definitions and Differences

1. Types of coal (JIS M1002)

1-1. Types of coal according to Japanese Industrial Standards

The types of coal defined in Japanese Industrial Standards (JIS) M1002 (1978) are categorized by their dry and ash free calorific values, fuel ratios according to their compositions, and cokeability into four broad classes (A, B/C, D/E and F) and nine narrow classes (A1 to F2).

The dry and ash free calorific value is the heat energy (MJ) produced by 1 kg of a portion of coal from which all moisture and ash has been removed. Whether these calorific values are gross (higher) calorific values or net (lower) calorific values is not mentioned in JIS M1002, the reason for which is unclear.

The fuel ratio is the ratio of the fixed carbon content of a coal's composition to the volatile content. Fuel ratios are calculated from fixed carbon contents and volatile contents measured by industrial chemical analysis.

Cokeability is a property of coal melting and fluidizing when heated strongly and then hardening to a solid residue. Cokeability is mainly used for judging the suitability of raw coal for steel production.

[Addenda Table 3-1-1. Classes of coal in JIS M1002 (extract)]

	Calorific value (corrected to dry and ash free basis)		Fuel ratio	Cokeability
Anthracite A	A	---	≥4.0	No
Bituminous coal B,C	B	≥35.16 MJ/kg	≥1.5	Good
	C	33.91–35.16	--	Yes
Sub-bituminous coal D,E	D	32.65−33.91	--	Poor
	E	30.56−32.65	--	No
Brown coal F	F	<30.56 MJ/kg	--	No

1-2. Classes of coal by standard calorific values and carbon emission factors

Standard calorific values and carbon emission factors for anthracite and brown coal (lignite or brown coal), which have greatly different characteristics from the other classes of coal described above, accord with the way they are classified.

However, using calorific values for the classification of bituminous coal, sub-bituminous coal, etc. would result in circular definitions. Therefore, coking coal, PCI coal, imported steam coal and indigenous produced steam coal are classified by types of use and production; then calorific values and carbon emission factors thereof are defined.

2. Measurement standards for coal

2-1. Measurement standards for coal

Five categories of measurement standards for coal are defined in in JIS M8810 (1994): wet coal, dry coal, moisture free, dry and ash free, and pure coal.

"Wet coal" refers to a state that is the sum of the fixed carbon content, the volatile content, the ash content and the total moisture (free water and equilibrium moisture) in a coal. This measurement standard is widely used for coals traded under names such as "wet coal (with moisture and ash)", "as received (basis)", "ar" and "as received wetted".

"Dry coal" refers to a state in which coal is dried and free water is removed from wet coal in accordance with JIS M8812. This corresponds to the sum of the fixed carbon content, volatile content, ash content and equilibrium moisture. This measurement standard is used in industrial chemical analysis under names such as "air dried (basis)", "air dry (basis)", "dry coal (with moisture and ash)", "as dried" and "ad".

"Moisture free" refers to measurements and calculations that subtract the equilibrium moisture from dry coal. This corresponds to the sum of the fixed carbon content, volatile content and ash content. This measurement standard is used in elemental analysis under names such as "moisture free basis", "dry" and "d".

"Dry and ash free" refers to measurements and calculations that subtract the equilibrium moisture and the ash content from dry coal. This corresponds to the sum of the fixed carbon content and volatile content. This measurement standard sometimes appears under names such as "dry and ash free basis", "dry and combustible matter free basis" and "daf".

"Pure coal" refers to measurements and calculations that subtract the equilibrium moisture and mineral matter from dry coal. This corresponds to the sum of the fixed carbon content and volatile content (excluding mineral matter). This measurement standard sometimes appears under names such as "dry mineral matter free" and "dmmf".

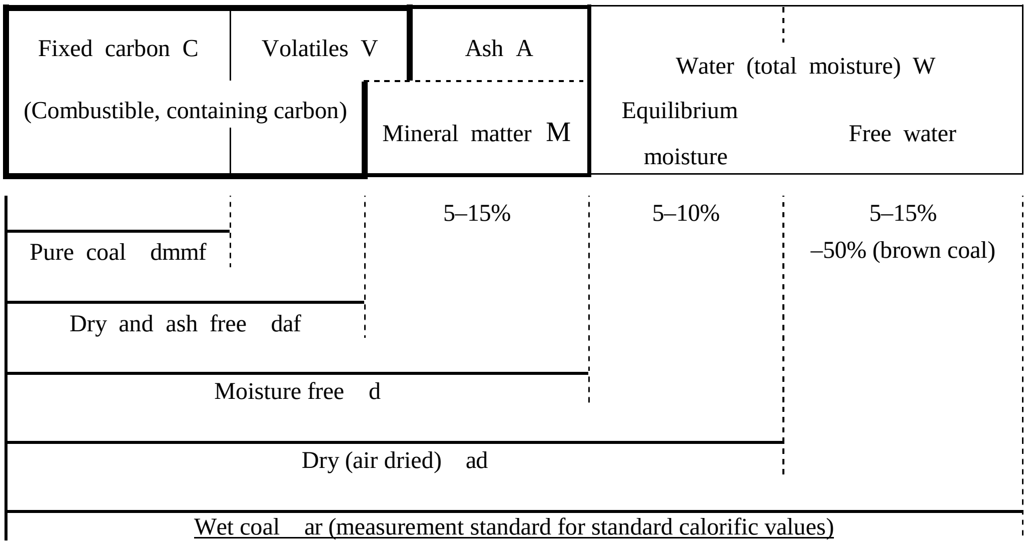
Other standards that are used, in fields such as biomass and construction, include "bone dry" (bd), which has been dried until no more water content evaporates at 105±5°C, and "moist mineral matter free" (mmmf) in accordance with the American standard ASTM D388 (1988), in which mineral matter is subtracted from dry coal.

2-2. Measurement standards and calorific values

The combustible components in the chemical composition of coal are accounted for by the fixed carbon content and the volatile content. Therefore, *calorific values measured by measurement standards that include larger amounts of ash and water are smaller;* the wet coal standard gives the smallest calorific values. In particular, because the net (lower) calorific value is more affected by latent heat due to water content, the difference between calorific values according to the wet coal standard and the moisture free standard is larger for the net (lower) calorific value than for the gross (higher) calorific value.

However, because ash content and water content do not contain carbon or combustible components, *carbon emission factors are the same under any of the measurement standards.*

[Fig. 3-2-1. Coal measurement standards and differences in scopes of measurement in relation to chemical composition]


Fixed carbon C
Volatiles V
Ash A
Water (total moisture) W
(Combustible, containing carbon)
Mineral matter M
Equilibrium moisture
Free water
5–15%
5–10%
5–15%
–50% (brown coal)
Pure coal dmmf
Dry and ash free daf
Moisture free d
Dry (air dried) ad
Wet coal ar (measurement standard for standard calorific values)

Note: This diagram illustrates the general concepts. See the relevant JIS documents for strict definitions. The numbers are for the dry coal standard but note that results in relation to equilibrium moisture depend on how the drying is done.

2-3. Standard calorific values and carbon emission factors and coal measurement standards

For the standard calorific values and carbon emission factors, the wet coal measurement standard is used for calculating gross (higher) calorific values and the corresponding carbon emission factors, because coal supply and demand figures in Trade Statistics of Japan and other energy statistics use the wet coal standard.

This measurement standard is also referred to as Gross and As Received (GAR) in English-speaking countries.

Addendum 4. Special Cases of the Calculation of Carbon Emission Factors for Blast Furnace Gas and Converter Furnace Gas

1. Production processes and characteristics of blast furnace gas and converter furnace gas (See Addenda Fig. 4-1-1)

1-1. Blast furnace gas

Blast furnace gas is a byproduct of iron production in a blast furnace during the steelmaking process. It is the gas that is recovered when iron ore is reduced by partial oxidation of coke or PCI coal fed into the blast furnace.

A blast furnace operates with coke and sintered ore being fed in from the top of the furnace and PCI coal and high-temperature, high-pressure air being fed in from the bottom of the furnace. Inside the furnace, it is known that very hot carbon from the coke at the top and carbon monoxide from the PCI coal at the bottom reduces iron oxide in the sintered ore to produce pig iron.

Carbon that is excess to the reduction process is converted into carbon monoxide and carbon dioxide and is recovered at the top of the furnace, together with nitrogen from the high-temperature, high-pressure air. This is blast furnace gas, about 50% nitrogen and about 20–25% each of carbon monoxide and carbon dioxide.

Blast furnace gas is used as a general energy source in ironworks and is also fed to power generation plants in ironworks and used as a fuel for electricity generation.

Some of the carbon derived from the coke and PCI coal fed into the furnace is absorbed into the iron. In this state, the pig iron containing 3–5% carbon is transported to the steelmaking process, where most of this carbon is converted into converter furnace gas in a converter furnace.

1-2. Converter furnace gas

Converter furnace gas is a byproduct of steel production in a converter furnace during the steelmaking process. It is recovered while excess carbon contained in pig iron is being removed by oxygen blowing.

The steel production process in a converter furnace decarbonizes and heats the pig iron by blowing oxygen over it ("smelting"). Thus, the pig iron containing 5.0–3.0% carbon is converted to crude steel containing 2.1–0.02% carbon.

The carbon from the pig iron is converted to carbon monoxide and carbon dioxide by the blowing oxygen, removed, and recovered as converter furnace gas. The converter furnace gas is about 65% carbon monoxide and about 20% each of carbon dioxide and nitrogen.

Converter furnace gas is used as a general energy source in ironworks, similarly to blast furnace gas, and is also fed to power generation plants in ironworks and used as a fuel for electricity generation.

A converter furnace has a different character from a blast furnace in that no energy source is supplied to the furnace itself. The process is sustained by the heat of the reaction between the carbon in the pig iron and the blown oxygen.

2. Issues in calculating carbon emission factors for blast furnace gas and converter furnace gas; three calculation methods

2-1. Issues in calculating carbon emission factors for blast furnace gas and converter furnace gas

One issue in calculating carbon emission factors for the byproduct gases of the steelmaking process (blast furnace gas and converter furnace gas) is the question of who is responsible for emissions of carbon dioxide that is contained in these byproduct gases from their formation and for emissions originating from carbon monoxide as a precursor of carbon dioxide.

Three methods are applicable to calculating the carbon emission factors, depending on how this question is to be addressed: the total carbon method, the combustible carbon method and the energy consumption allocation method.

2-2. The total carbon method

The total carbon method is a carbon emission factor calculation method that takes the approach of treating all the carbon dioxide, including the carbon dioxide contained in the byproduct gases from their formation, as emissions by the final user.

In the total carbon method, for example, if byproduct gas is sold by a steelmaking company to an electric power company and used for electricity generation, all the carbon dioxide, including carbon dioxide contained in the byproduct gas from its formation, is treated as emissions by the electric power company.

One advantage of the total carbon method is that calculation is easy provided the carbon contents and quantities of the byproduct gases are known. Therefore, the system of calculation is extremely clear and simple.

For this reason, the United Nations Framework Convention on Climate Change greenhouse gas inventory (UNFCCC-GHGs Inventory) and various calculation guidelines and such from the IPCC are premised on the total carbon method[*29].

One disadvantage of the total carbon method is that emissions contributions such as carbon dioxide that has been present from the formation of the gas are accounted for as emissions by the final user, such as the electric power company in the above example, even though it did not itself contribute to the emissions, while the actual emitter (the steelmaking company) avoids any accounting for the emissions. Conversely, if there is investment in new equipment for a furnace and emissions are reduced, the emissions reduction is assigned to the final user.

2-3. The combustible carbon method

The combustible carbon method is a calculation method that takes the approach of treating the carbon dioxide contained in the byproduct gases from their formation as emissions by the initial user and combustible components (carbon monoxide and residual hydrocarbons) as emissions by the final user.

In the combustible carbon method, for example, if byproduct gas is sold by a steelmaking company to an electric power company and used for electricity generation, the carbon dioxide contained in the byproduct gas is treated as emissions by the steelmaking company but emissions originating from the combustible components in the byproduct gas are treated as emissions by the electric power company.

One advantage of the combustible carbon method is that only the portion of the byproduct gas that the final user, such as the electric power company, exploits for combustion energy is calculated as its emissions contribution, while the carbon dioxide that the initial user, such as the steelmaking company, actually emits itself is calculated as its emissions contribution.

One disadvantage of the combustible carbon method is that allocation of the carbon dioxide in the byproduct gases must be calculated and assigned to the emissions contributions. Therefore, the number of statistical items that must be collected is greater and the calculation is more complicated than in the total carbon method.

A further point is that although the initial user such as a steelmaking company gains the benefit of the energy of partial combustion to carbon monoxide, the precursor of carbon dioxide, the initial user does not directly produce that carbon dioxide. Therefore, this carbon dioxide is still entirely accounted for as emissions from the final user such as an electric power company.

2-4. Energy consumption allocation method

The energy consumption allocation method is a calculation method that takes the approach of allocating the carbon content contained in the energy source that is initially fed in as raw material for the byproduct gases, including both the carbon dioxide contained in the byproduct gases from their formation and the carbon monoxide that is a carbon dioxide precursor, in accordance with energy consumption amounts by the initial user and the final user and treating the allocated carbon content as the respective emissions.

In the energy consumption allocation method, for example, if byproduct gas is sold by a steelmaking company to an electric power company and used for electricity generation, the carbon content of the energy source that is the raw material when the byproduct gases are produced (coke, PCI coal or the like) is allocated in proportion to the energy consumption amounts associated with the byproduct gas by the steelmaking company and the electric power company, and the allocation of the contents are treated as the respective emissions.

One advantage of the energy consumption allocation method, in addition to the advantages of the combustible carbon method, is that the emission contributions of the precursor carbon monoxide are divided between and accounted for by the final user and the initial user in accordance with energy consumption amounts.

Some disadvantages of the energy consumption allocation method are that the number of statistical items that must be collected is even greater than in the combustible carbon method, the calculations are extremely complicated because the steelmaking process itself must be considered in the calculations, and the actual carbon usage diverges greatly from the emissions contributions.

[*29] Similarly, all emissions contributions relating to electric power and heating are assigned to the electric power or heating business under the UNFCCC and IPCC, but Japan's Act on Promotion of Global Warming Countermeasures, among others, states in Article 2, Paragraph 4 that "emissions ... shall mean ... the use of electric power or heat ... that is supplied by others". In these matters, there is a difference in the basic approach to calculating direct contributions to emissions.

3. Carbon emission factor calculation methods for blast furnace gas and converter furnace gas; specific applications

3-1. Carbon emission factors of blast furnace gas

Carbon emission factors for blast furnace gas have been calculated from energy supply and demand amounts in the annual General Energy Statistics using the energy consumption allocation method as in the past.

Because blast furnace gas is produced from coke or PCI coal fed into blast furnaces, the carbon emission factors of blast furnace gas are calculated from blast furnace energy and carbon balances by the following procedure.

1) The gross (higher) calorific value of blast furnace gas is calculated from its composition and physical properties. An annual total energy generated by blast furnace gas is calculated.
2) The amounts of coke and PCI coal directly required for generating the annual total energy of the blast furnace gas calculated in 1) are estimated from feed rates of coke and PCI coal into blast furnaces.
3) The amount of carbon contained in the amounts of coke and PCI coal directly required to produce the blast furnace gas calculated in 2) is calculated. This carbon amount is subtracted from the annual total energy generated by blast furnace gas to calculate a carbon emission factor for blast furnace gas.

In General Energy Statistics, in order to prevent double counting, the energy and carbon amounts of the coke and PCI coal directly required for the generation of the total energy generated by blast furnace gas are subtracted from the consumption and emissions of coke and PCI coal; the rest of the coke and PCI coal inputs are consumed and emitted by the blast furnaces. That is, because energy generated by the carbon dioxide contained in the blast furnace gas is zero, the carbon dioxide is all treated as consumption and emission in blast furnaces. The coke and PCI coal corresponding to precursor carbon monoxide is allocated to generated energy amounts and calculated as consumption and emissions at blast furnaces and power generation plants.

3-2. Carbon emission factors of converter furnace gas

Carbon emission factors for converter furnace gas have been calculated using the combustible carbon method as in the past.

Converter furnace gas basically should be calculated using the energy consumption allocation method, similarly to blast furnace gas. However, unlike a blast furnace, there is no direct input of an energy source to a converter furnace, and it is very difficult to calculate energy and carbon balances for the carbon contents of pig iron, crude steel and scrap iron. Therefore, the energy consumption allocation method cannot be employed on the basis of energy and carbon balances. This is why the combustible carbon method has had to be used previously.

In specific terms, the gross (higher) calorific value and carbon content per original unit amount are calculated for the components of converter furnace gas, excluding carbon dioxide, from their compositions and physical properties. A carbon emission factor is calculated by dividing the carbon content by the gross (higher) calorific value.

In General Energy Statistics, in order to prevent double counting, the annual generated energy and carbon amounts of converter furnace gas are calculated, and the respective amounts of coke and PCI coal directly required for these annual generated energy and carbon amounts of converter furnace gas are estimated from proportions of the inputs of coke and PCI coal to blast furnaces and are subtracted from the energy consumption and carbon emission amounts of blast furnaces.

3-3. Carbon emission factors of coke oven gas and refinery gas (for reference)

Carbon emission factors for coke oven gas and refinery gas have been calculated using the total carbon method as in the past.

The reason for using the total carbon method is that, unlike blast furnace gas and converter furnace gas, the carbon monoxide and carbon dioxide components in these byproduct gases are relatively small, as shown below. Therefore, choosing to use the combustible carbon method or the energy consumption allocation method would require complicated calculations of contributions in a number of different fields for very little benefit.

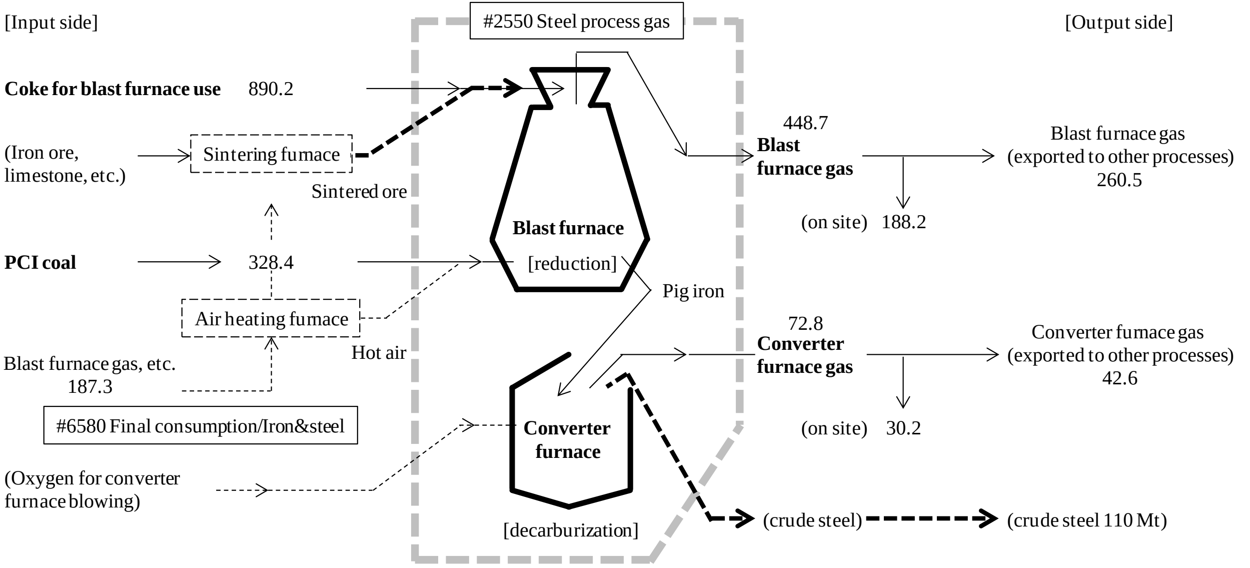
- Unlike blast furnace gas and converter furnace gas, coke oven gas and refinery gas are byproduct gases from conversion processes whose objectives are not the use of energy for reduction or heating.
- The carbon monoxide and carbon dioxide contents of coke oven gas and refinery gas are at most 6% and on average 1–2%, which are relatively small.

- Most refinery gas is consumed on-site by the oil refining industry.

[Addenda Table 4-3-1. Differences between the carbon emission factors of blast furnace gas and converter furnace gas according to the calculation methods (standard values are underlined)]

	Calorific values (MJ/m^3 at SATP, MJ/kg)				Carbon emission factors (gC/MJ at SATP)					
	By volume		By mass		Total carbon		Combustible carbon		Energy consumption allocation	
	Gross (higher)	*Net (lower)*	Gross (higher)	*Net (lower)*	Gross (higher)	*Net (lower)*	Gross (higher)	*Net (lower)*	Gross (higher)	*Net (lower)*
Blast furnace gas	3.28	*3.14*	2.64	*2.52*	71.31	*74.71*	35.66	*37.35*	26.13	*27.37*
Converter furnace gas	7.64	*7.60*	6.18	*6.15*	51.94	*52.19*	41.72	*41.92*	(calculation is difficult)	

[Addenda Fig. 4-1-1. Energy balances of blast furnace gas and converter furnace gas]
(Unit PJ, actual 2010 values from General Energy Statistics)


[Input side]
#2550 Steel process gas
[Output side]
Coke for blast furnace use
890.2
(Iron ore, limestone, etc.)
Sintering furnace
Sintered ore
448.7
Blast furnace gas
Blast furnace gas (exported to other processes)
260.5
(on site) 188.2
Blast furnace
PCI coal
328.4
[reduction]
Pig iron
Air heating furnace
Hot air
Blast furnace gas, etc.
187.3
#6580 Final consumption/Iron&steel
72.8
Converter furnace gas
Converter furnace gas (exported to other processes)
42.6
(on site) 30.2
Converter furnace
(Oxygen for converter furnace blowing)
[decarburization]
(crude steel)
(crude steel 110 Mt)

Note 1. See Addendum 3 in reference 5, Kainou (2010) "Interpretation of General Energy Statistics" for details.

Note 2. Numbers prefixed with "#" are class numbers in General Energy Statistics.

Addendum 5. Calorific Values during Consumption of Electricity and Primary Conversion Input Calorific Values (Generation End and Receiving End)

1. Calorific values during consumption of electricity

1-1. Calorific values during consumption of electricity

According to definition, the amount of heat generated when 1 kWh of electricity is consumed is 3.60 MJ.

This relationship is based on the fact that the unit of heat, the Joule (J) is 1 Watt (W) for 1 second.

$$1\ \mathrm{J} \equiv 1\ \mathrm{W{\bullet}s},\ \therefore\ 1\ \mathrm{kWh} = 1000 * 1\ (\mathrm{W{\bullet}s}) * 3600\ (\mathrm{s/h}) = 3.60\ \mathrm{MJ}$$

Therefore, the standard calorific values for heat amounts generated during consumption of electricity are 3.60 MJ/kWh for both the gross (higher) calorific value and the net (lower) calorific value.

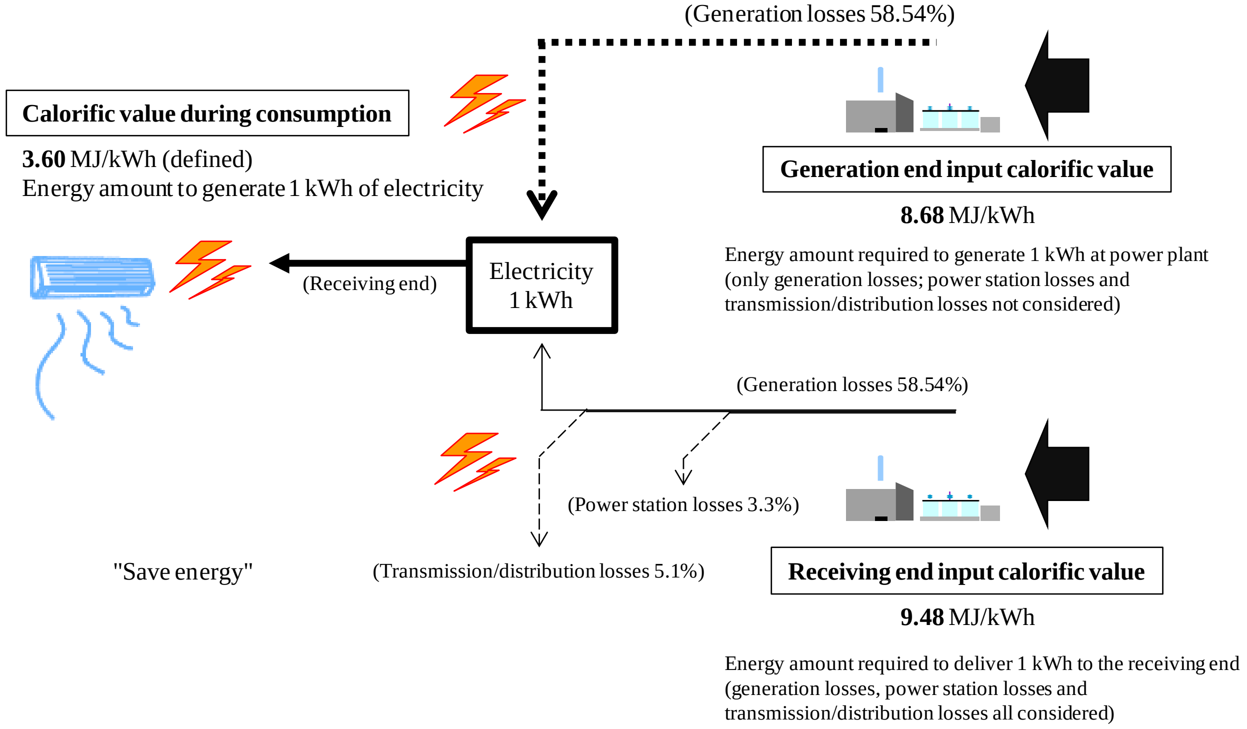
2. Primary conversion input calorific values of electricity

2-1. Concept of primary conversion input calorific values of electricity

In electricity generation, to supply 1 kWh (3.60 MJ) of electricity to the consumption side it is necessary to input at least enough energy to cover generation losses at the supply side, losses within the power station, transmission and distribution losses, and so forth.

A calorific value of electricity taking account of the energy amounts that must be input at the supply side is referred to as the primary conversion input calorific value; depending on which losses are being taken into consideration, it is categorized as the generation end (primary conversion) input calorific value or the receiving end (primary conversion) input calorific value.

[Addenda Fig. 5-2-1. Concepts of calorific values in electricity generation]


(Generation losses 58.54%)
Calorific value during consumption
3.60 MJ/kWh (defined)
Energy amount to generate 1 kWh of electricity
Generation end input calorific value
8.68 MJ/kWh
Energy amount required to generate 1 kWh at power plant
(only generation losses; power station losses and
transmission/distribution losses not considered)
(Receiving end)
Electricity
1 kWh
(Generation losses 58.54%)
(Power station losses 3.3%)
"Save energy"
(Transmission/distribution losses 5.1%)
Receiving end input calorific value
9.48 MJ/kWh
Energy amount required to deliver 1 kWh to the receiving end
(generation losses, power station losses and
transmission/distribution losses all considered)

Note: Generation losses, power station losses, etc. are average values for FY2008–2012.

2-2. Differences and applications of primary conversion input calorific values of electricity (generation end and receiving end)

The generation end input calorific value is a primary conversion input calorific value that takes account only of standard generation losses. It is used when power is supplied by home generation close to the consumption side and when, for whatever reasons, there is no need to separate out and take account of power station losses and transmission and distribution losses.

The receiving end input calorific value is a primary conversion input calorific value that takes account of all of standard generation losses, power station losses, transmission and distribution losses, etc. It is commonly used when a supply of power is received from an electric power company through a transmission and distribution system.

2-3. Calculation results of primary conversion input calorific values of electricity

These generation losses, power station losses, and transmission and distribution losses are calculated using average thermal power generation losses, (power) station losses, and transmission and distribution losses of General Electric Utilities according to Electric Power Statistics.

The current generation end input calorific value, calculated on the basis of loss rates according to Electric Power Statistics, is 8.81 MJ/kWh and the current receiving end input calorific value is 9.68 MJ/kWh.

In the current revision, new generation end and receiving end input calorific values are calculated as described below on the basis of average values of loss rates according to Electric Power Statistics from 2008–2012[*30].

Reliability statistics such as the standard deviation and the standard error can be estimated from yearly variations in loss rates from 2008–2012. Therefore, the upper and lower limits of the 95% confidence intervals for the generation end and receiving end input calorific values are calculated using the yearly variations in this time series.

In the results, both the current generation end and receiving end input calorific values fall beyond the upper limits of the 95% confidence intervals of the new calculated values. Therefore, it will be appropriate to update both the gross (higher) calorific values and net (lower) calorific values in accordance with the new calculated values to generation end input calorific values of 8.68 MJ/kWh and receiving end input calorific values of 9.48 MJ/kWh.

[Addenda Table 5-2-3. Calculation results of generation end primary conversion input calorific values and receiving end primary conversion input calorific values]

MJ/kWh, FY	2008	2009	2010	2011	2012	Mean	SD	95% CI
Average thermal power generation loss	0.413	0.418	0.416	0.414	0.413	0.415	0.002	0.417/0.412
Generation end (primary conversion) input calorific value	8.711	8.621	8.659	8.705	8.719	8.683	0.042	8.735/8.631
Power station and transmission/distribution losses	0.087	0.088	0.084	0.084	0.080	0.084	0.003	0.089/0.080
Receiving end (primary conversion) input calorific value	9.542	9.454	9.448	9.503	9.473	9.484	0.039	9.532/9.436

FY: fiscal year, SD: standard deviation, CI: confidence interval

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[*30] At the time of the revision of standard calorific values in FY2005, actual values for the single year of FY2004 were used for the calculations. However, in light of the effects of the Great East Japan Earthquake of 2011, the current revision uses the average over five years.

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Acknowledgements

The calculations of calorific values, carbon emission factors, and interpolation and approximation equations in this paper would have been completely impossible without accurate measurements. I am very grateful to each of the relevant industrial organizations and associated businesses who cooperated in measurement surveys at the request of the Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry and the Global Environment Bureau, Ministry of the Environment.

Conducted measurements and provided data (in no particular order):

- Japan Iron and Steel Federation
- Federation of Electric Power Companies of Japan
- Petroleum Association of Japan
- Japan Natural Gas Association
- Japan Paper Association
- Member companies of Japan Chemical Industry Association

Assistance with documentary resources:

- National Astronomical Observatory of Japan, National Institute of Natural Sciences
- Japan Gas Association

I am also grateful to the following for their cooperation and helpful suggestions: the officials of the Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry and the Global Environment Bureau, Ministry of the Environment; the General Energy Statistics committee, Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry; and the members of the Energy and Industrial Processes subcommittee of the Committee for the Greenhouse Gases Emissions Estimation Methods, Global Environment Bureau, Ministry of the Environment.